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MIDSUMMER NIGHT IN THE ARCTIC OCEAN, NORTH OF BEHRING STRAIT

(AFTER A WATER COLOUR PAINTING BY Dr PECHUEL-LOESCHE).

OUR EARTH AND ITS STORY:

A Popular Treatise on Physical Geography.

EDITED BY

ROBERT BROWN, PH.D., F.L.S.,

AUTHOR OF "THE PEOPLES OF THE WORLD," "THE COUNTRIES OF THE WORLD," ETC. ETC.

*

WITH TWELVE COLOURED PLATES AND MAPS AND TWO HUNDRED WOODCUTS.

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PREFACE.

In preparing a work which should form at once a complement and an introduction to the Editor's treatises on the Ethnology and Political Geography of the World, it was at first thought that this end might be suitably attained by a translation—with some additions, abridgement, and other modifications—of the "Allgemeine Erdkunde" which forms the first three sections of Professor Alfred Kirchhoff's "Unser Wissen von der Erde." Of this work, the Geology was written by the late Dr. Ferdinand v. Hochstetter, the Biological Geography by Dr. Alois Pokorny, and the Meteorology, "Geo-physics," and Astronomy, by Dr. Jul. Hann—all men of pre-eminent fitness for the task allotted to them. But after going more critically into the subject, it was found advisable to depart from this intention. The "Allgemeine Erdkunde" is written too completely with an eye to the wants of Germany and especially of South Germany, to render it of much value to English readers without many important modifications. Facts and theories, illustrations and the relative importance of the subjects described, are too exclusively selected from Austria and the Eastern Alps, or are so carefully reduced to the meridian of Vienna, as to make them only partially intelligible to those whose homes are in Great Britain, America, or the British Colonies. Questions of purely local or technical interest are discussed at inordinate length, while others of greater concern to the reader for whom this series of works is intended, are dismissed with undue curtness, or are altogether neglected. In some cases, also, the writers give currency to opinions or advocate views which the Editor could not take it upon himself to support; and in nearly every instance the style of the German writers lacks something of that lucidity essential in a book which is not prepared for geologists or geographers, but for those whose acquaintaince with Physiography is of an elementary character.

Accordingly, the changes which have been made are tantamount to a complete re-writing of the original treatise, and, so far as the first volume is concerned, to

the composition of what is, to all intents and purposes, an entirely new work. Nothing of the original has been retained, except what relates to the illustrations, and even these have been supplemented by many new cuts, with the object of rendering the text more easy of comprehension.

In a work of this sort, which is the digest of a science to the archives of which hundreds of observers have contributed, the Editor must necessarily draw for his materials on many memoirs in many languages. These, he hopes, have in every case been duly acknowledged, except, of course, where the phenomena described are patent to every one. If, in an exceptional instance, he has inadvertently failed to refer any fact to its proper source, he can only explain that a considerable portion of the first volume is based upon his own prelections while Lecturer on Geology and Physical Geography in the Watt-Heriot College (School of Arts), Edinburgh. It may therefore have occasionally happened that, in dealing with data so numerous, a circumstance may have been quoted without the authority for it having been noted at the time. This, however, must be of rare occurrence.

The Editor has only to add that though no section of the work is intended to play the part of a text-book on the subject, or to replace more special treatises, he trusts not to have omitted any discovery of essential importance among the many which he has gleaned from all accessible sources of information, among which his own observations and the correspondence of friends in many parts of the world may be allowed a prominent place.

R. B.

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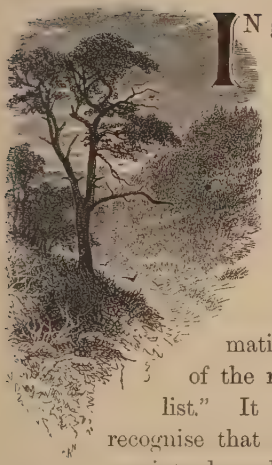
Our Earth and its Story.

INTRODUCTION.



IN glancing round the world, the individual who has not been trained in the school of science is apt, at the outset, to imagine that "nothing in this earthly ball is like another all in all"; that everything is, as it were, by itself, without much relationship with the objects which surround it. There is dead matter and living matter; there are objects animate and objects inanimate; materials which are solid, liquid, or gaseous; creatures which are born, grow, wane, and die; and the hills, which from age to age seem never to change. Again, he is prone to conclude that while "living" Nature is constantly undergoing some transformation, the inanimate portion of creation is stable, with the exception of the rivers, and the waves, and the winds which "blow whither they list." It does not come within the purview of the untaught observer to recognise that the plants, and the animals, the sun, the moon, and the stars, are interdependent; that the shape of a country affects the clouds which soar over it; or that a range of hills or an expanse of plain are the leading factors in the wealth of one nation or in the culture of another. But by-and-by he discovers that they are all members of a single system, that the one could not exist without the other, and that the farmer who ploughs his fields far away from the roar of the "many-sounding sea" could not reckon on reaping his crop in the fulness of time, without the beneficent influence of that ocean which encircles itself with barren sand. In like manner, a study of the science which it is the purpose of these pages to unfold teaches us that the Arctic glacier, which grinds its rugged way to the sea, is dependent for the ice which feeds it on the same influences which send the Amazon rolling through the Tropics, or covers the corn-lands of England with yellow grain. A movement of which we are unconscious makes half of a continent a blooming forest for six months of the year and a snowy waste for the remainder; and, just as a trifling eccentricity of the Earth's orbit has rendered Northern Europe habitable, so an equally slight twist may again bring back the Glacial period and the concomitants of the mammoth. In brief, the forces of Nature, which have acted in exactly the same way from the beginning of Time until now, are so much members of one harmonious whole that the absence of one member of the system—an element seemingly of little moment—is disastrous to the remainder. It is

as if a pin should be removed from a machine: the whole would either stand still, or, sooner or later, cease to act with either comfort or advantage.

This fact—which to a naturalist is so elementary as to be little better than a truism—does not seem to be always grasped by the poet or the painter. The rhymers whom Pope scarified in the "Dunciad" make, for example—

> "In cold December fragrant chaplets blow,
> And heavy harvests nod beneath the snow."

But a closer observer of Nature than the poets of whom Elkanah Settle was the Laureate is occasionally quite as far astray. Take, for instance, Tennyson, in that passage which must be familiar to every one where Arthur tells "the bold Sir Bedivere" that he is going a long way with the weird women—

> "'To the island-valley of Avilion,
> Where falls not hail, or rain, or any snow,
> Nor ever wind blows loudly; but it lies
> Deep-meadowed, happy, fair with orchard-lawns
> And bowery hollows crowned with summer sea,
> Where I will heal me of my grievous wound.'"

Such a spot might exist in Fairy Land; in any region more prosaic it would be impossible. Passing over the fact that the existence of the summer sea would all but necessitate the existence of rain from evaporation, and that the valley presupposes mountains which would precipitate the moisture-laden clouds, it is clear that without rain there could be no "orchard-lawns," and that an island-valley where the wind never blows would in time get so pestilential that, so far from being a spot where the king could heal him of his grievous wound, it would be a death-trap. In brief, accepting the Laureate's premisses, the physical geographer, who must eschew fancies in favour of realities—which, rightly considered, are quite as sublime—can only conclude that the island-valley of Avilion, if subject to the ordinary laws of Nature, must have been—

> "a waste land, where no one comes,
> Or hath come since the making of the world."

Yet the dependence of one force of Nature on another is so beautiful that, if the painter who portrays a background of American plants to a picture relating to an incident which happened before Columbus sailed on his famous voyage, or makes birds disport themselves amid vegetation which belongs either to a country different from that which they inhabit, or in a condition which at once shows that they must have at that particular period been in their winter quarters, where very different surroundings obtain, if he would consider the necessities of the case, he would derive more pleasure from the composition of his work than the scientific critic from the analysis of it. There is, of course, no more reason why the Polar bear should have its home amid ice and snow than the brown species amid pine forests. And, except that Nature has ordered it differently, the modern elephant might as lief live in Siberia, as its woolly kindred did when the world was younger than that of which we have personal knowledge. If, however, the environments of each animal are studied, it will be found that there are circumstances

which render the home of each more appropriate to it than could be any other habitat, and that this appropriateness is due to the close interdependence of a host of elements, animate or inanimate. The explanation of what these are, how the one acts and reacts, opens out the whole field of physical geography—or, as it is sometimes called, "physiography," to distinguish the description of the world in a state of Nature, and the forces which have made and kept it so, from that geography which consists of a description of the Earth as divided into territories, influenced, altered, and, it may be, transformed by man and his works. The causes which have made the South American Desert of Atacama (Fig. 1) a waterless waste, and the laws which enable a certain amount of life to exist there, constitute one department of the science; the modern enterprise which has burrowed it with mines, run a railway across it, and has thus rendered it an object of contention between the three nations around it, constitutes the other and more human section of the Earth's description.

The Living Earth.

The ancients fabled the world in which we live to be an animate, sentient being; and though possibly, according to the definitions of life which modern biologists have accepted, this opinion of the philosophers "who were older" and sometimes even "wiser than we," must be dismissed as untenable, yet, in some respects, "the Earth and the waters under the Earth" show more mobility than many animals, and greater internal activity than most plants. The Earth is never at rest. It has undergone and is undergoing endless vicissitudes. The matter of which it is formed, though seemingly the model of all that is unchangeable, is in reality often in a state of perturbation and transformation. Not a grain of the solid matter of the globe was originally in the form which it at present assumes. What is now solid was formerly liquid; what is at this moment in the shape of rocks deeply bedded, and far out of sight of the sea, was, in a remoter period of the world's history, formed by sediment deposited at the bottom of the ocean, or on the bed of some long-vanished lake. The "mould" on which flourish luxurious crops of plants, was at one time the *débris* of a rank vegetation, which grew on some still deeper soil. The hard beds of coal are the indurated and altered remains of forests which existed long before the human era of the world had begun to dawn. The vast reservoirs of petroleum were, on the other hand, most probably the tangible evidences of a great natural distillation of plants, which commenced at a date which it is vain to conjecture, and which, measured by our standards of chronology, would be too vague for comprehension. Every shower of rain which sweeps along the mountain side wears down the soil, and more or less appreciably alters the conformation of the country. The muddy river which flows to the sea carries with it a still more appreciable amount of the soil into which it cuts, to lay it as the foundation of the lands that are to be miles possibly from the shore where it mingles its flood with the waters of the parent ocean. Indeed, it has been calculated that at the present rate of denudation, or wearing-away, the Andes will have disappeared in from 9,000,000 to 156,000,000 years, though, were the denuding influences of the globe concentrated on

them alone, this great range would be swept from the American continent in 135,000 years, since the rate of wearing-away varies in certain river-basins from one foot in 700 years to one foot in 12,000 years, though, of course, in the case of waterfalls like that of Niagara, or when the circumstances are unfavourable for the soil in its battle with the water, the destruction is accomplished in a much more speedy manner.

But this grinding-down action is never permitted to act alone. There is no such thing as monopoly in Nature. The earthquake may rend the rocks asunder, and make in a few seconds a frightful havoc of the puny labours of man during many centuries. Yet the volcano is ever and again vomiting up islands and mountains from the centre

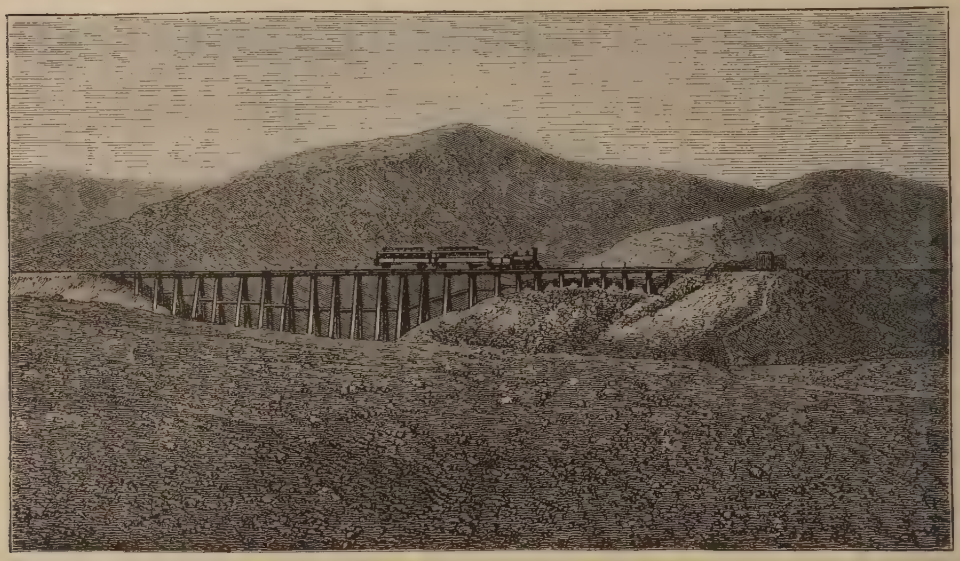


Fig. 1.—THE DESERT OF ATACAMA (SOUTH AMERICA).

of the globe; while the coral polyp, less slowly, but not less surely, is in like manner adding to the surface of dry land fit for human habitation. The Earth is, in truth, never at rest. If only the more violent of the movements of Enceladus, the imprisoned giant of classic times, are noticed and recorded in a people's chronicles, there is probably no period at which some movement is not in progress. As we shall learn by-and-by, there are portions of the Earth which are slowly sinking, though the depression is so gradual that it is only after long intervals that the fact can be demonstrated by the disappearance of marks made on rocks lying off the coast affected; while other sections, often in immediate contiguity, are just as slowly rising. But an examination of some of these localities, such as a district in Southern Sweden, proves that the reverse process had at one period been in progress—in other words, that the region now sinking was then rising, and *vice versâ*. It thus appears that the poets are wrong again. It is the sea which is stable; it is the land which is unstable.

Yet though the sea, by the equilibrium of the forces concerned, manages to preserve

its level, it is by no means exempt from that constant change which it is the law of Nature for every created thing to undergo. The sea is the creation of the rains and the rivers, and the rains, and their offspring the rivers, are equally dependent on the evaporation which is continually rising from the sea. Were not this ceaseless interchange taking place, the great lakes and the sea itself would become like the "painted ocean" of the "Ancient Mariner;" it would become stagnant, putrefy, and in time disappear. The inland lakes seem never much bigger or much smaller, taking one season with another. But they

Fig. 2.—THE DEAD SEA (PALESTINE).

would soon be dry were it not for the rivers which feed them. In northern climates this supply, which flows in from the drainage, either in the form of rivers or of springs, which are only forms of the same thing, is more than equal to the evaporation, and in part, at least, flows out again in the form of a second river. But in drier regions this does not happen. Hence the Dead Sea (Fig. 2) and the Great Salt Lake of Utah, though fed by rivers, never overflow, in spite of the fact that they have no defluents, the tribute which the sun claims by evaporation being sufficient to keep up their equilibrium. In some parts of the world, as in Central Asia, are found the dried-up beds of lakes which have disappeared; and in many other regions, where the timber has been recklessly destroyed, the rainfall has diminished, and with it the size of the rivers, while every here and there dark loamy places appear, where, at some former period, lakes have evidently existed. This, according to the writer's observations, is true, among other countries, of Morocco and the Barbary States generally.

But it is self-evident that neither the rivers nor the springs which feed the great "standing" accumulations of water could exist, were it not for the evaporation from the surface of the latter, or in a less degree from the soil on which the rain falls before it sinks into the earth to form the reservoirs of springs. This vapour, raised up by the action of the sun, accumulates in clouds. Some of these clouds impinge on the top of Alpine peaks, or drift into the far North, where they discharge their contents—or rather, their substance—in the shape of snow. This snow, accumulating in lofty regions during the winter more quickly than it is dissolved during the summer, forms a glacier which, slowly descending into the warmer valleys, is dissolved, and adds its water to the sub-glacier streams, which by-and-by join the glacier rivers, eventually to find its way to the sea, from which it originally sprang, though in the course of its ceaseless transformation it has undergone more inorganic metempsychoses than Gautama Buddha. If it is blown into the Polar air, it equally descends in the form of snow, which, contributing to that "inland ice" of the Arctic continent and islands, gives birth to the glaciers which, reaching the sea, release themselves in the guise of icebergs. These icebergs again float southward and, melting under the heat of the sea and the atmosphere, are resolved into the native elements which, after hovering in cloudland, fall either in rain, or hail, or snow, in torrents on the steaming plains of Bengal, or in chilly blasts on the frozen cliffs of Greenland. But the materials with which Nature works, seemingly so diversified, actually so few, are never at peace. They know neither haste nor rest. They are ever in circulation. No sooner have they served one purpose than they are called upon to appear in another *rôle*. A lake is fresh simply because its waters are constantly changing. But had it no outlet, like the Dead Sea or the Utah Lake, it would be impregnated with the salt and other substances which the springs and the streams which feed it wash out of the soil, and which are not carried up with the evaporation from the surface. The sea is salt on this account. It is fed by many rivers, and has an immense evaporating surface, but of course there are no outlets. The rivers hasten to make a lake in every hollow. Yet these hollows are in many instances scooped out by the action of glaciers. However, no sooner are they filled with water than the very glaciers which excavated their basins, and the rivers which filled them conspire to turn them once more into solid land.

We see this specimen of the ceaseless activity of Nature in many shapes. The "loess," or the mud, held in suspension by the rivers which overflow their banks, and which is eventually deposited, forms a well-marked geological formation over a considerable section of Central Europe; and the mud of the Arctic glaciers, which, as has been shown elsewhere,* finds its representative in the ancient fossiliferous brick-clays of Scotland and other regions where in the Glacial period a similar condition of affairs obtained, is fast filling up many of the fjords into which the infra-glacier stream discharges. The Baltic is fast becoming a shallow lake. The Sea of Azof, shoaled by the sediment brought down by the rivers which flow into it, is gradually being converted into a stream; and the Po, the Nile, and the other rivers which flow into the Mediterranean, bid fair to so extend their deltas as to constitute that sea a chain of lakes. The Mississippi and other great American

* "Arctic Papers of the Royal Geographical Society," pp. 1—74; "Countries of the World," Vol. i., pp. 52—67; Petermann's *Geographische Mittheilungen*, October, 1870; and *Quarterly Journ. Geol. Soc.*, Vol. xxvii. p. 671.

rivers are, on the principle of "robbing Peter to pay Paul," extending the territory through which they flow for considerable distances into the Atlantic. In time these mud flats will rise above the surface, get covered with a dank vegetation and, after being for ages the home of fever and reptiles, will become the abode of man. The Rhine, it has been calculated, carries past Bonn something like 400 tons of solid matter in one hour, and in the course of a year between three and four millions. In the long ages since this wearing-down of Germany has been going on, an immense amount of land must have been eroded, and deposited into the German Ocean, where it forms the greater part of the country now known as Holland. "The Netherlands," Napoleon Bonaparte asserted, in his usual dogmatic manner, "are composed of the mud of French rivers." And as it is not easy to answer the master of many legions except after his own style of argument, he proceeded to annex Batavia to the Empire. During the rainy season of 122 days the mud brought down by the Ganges passing Ghazeepoor, 500 miles from its mouth, is reckoned at over 339,413,700 tons; and now plague-haunted islands, formed in its channel even within the memory of man, are the result. The deltas of the Volga, the Danube, and many other rivers, might be adduced in proof of the same trait, were not these remarks intended merely as the introduction to a subject which will be more fully discussed in the chapters which follow. But before leaving it, the familiar example of the Rhône may be cited as a striking instance of this ceaseless, this unwearying interchange of matter—of the vitality, as it were, of this misnamed "stable" land. The Rhône, charged with glacial mud, enters Lake Geneva turbid, but issues from it clear; the whole of the detrital tribute which it has received from the muddy stream of the Alps having been deposited in the lake, where it has already aided in the formation of an alluvial plain five or six miles long. Port Valais, which eight centuries ago was actually a port, is now one mile and a half distant from the water's edge. And here a very curious fact, which has only lately come to light, may be mentioned in illustration of this same subject. Some time ago Herr Hoernlimann, engineer to the Swiss Federal Topographical Bureau, came to the conclusion that the channel of the Rhine goes through Lake Constance and under its waters—in other words, that the river has cut itself a bed in the floor of the lake, which is continued to its lowest depths. A similar condition of affairs has been found to prevail in the Lake of Geneva, or Lake Leman, as it is often called. The river runs in an actual ravine, having parallel banks, like the bed of an overground stream, this ravine having been scooped out by the force of the current entering or passing through the lake.

However, as we have seen, Nature is jealous of any one of her forces acting for an hour alone. The balance must be kept true by the antagonism of her forces, the one which tears down a made land in order to make a new one, being, as soon as its work is complete, met by another, which begins the labour anew. The volcano, the slow, "secular rise," and the coral polyp have elevated an island, or a section of country, above the surface of the waves. But it has no sooner appeared in the supra-aqueous world, than the sea begins to attack it, and toss its materials hither and thither, forming out of a solid peninsula strings of islands or an archipelago of mud flats, such as are witnessed

in the Frisian Islands and Holland.* We also see this in the way mountains are formed. It is quite incorrect to apply the term "old" to "the hills." In a geological sense many of them are infinitely newer than the plains, and the physical geographer is well aware that they are anything but "everlasting." They are, in fact, the offspring of rivers which cut up plains into elevated plateaux, of rains which crumble the plateaux into peaks, and of volcanoes and volcanic action which toss up into gigantic mounds the materials which the rivers have for ages been bringing down to the sea, and which the earthquake and the slow, "secular rise" have elevated from the bottom of the ocean or the lake. In a comparatively rainless region, such as that through which the Colorado flows, this eroding action of a river has all its own way. Without its work being neutralised by the play of the rain on the surface washing down the banks, the current wears down its bed, eating deeper and deeper into the soil, earth and rocks alike, until, as in the now well-known cañons of the Colorado and its tributaries, the river flows at the bottom of a cleft more than a mile below the level of the surrounding country (Fig. 3).

Yet the winds do not always bring rain and fertility. They may not bear on their blasts those children of the plain and the sea which we know as the clouds, or the clouds may sail over the parched land without bestowing on it the moisture of which they are composed. Not unfrequently they bring desolation in their track if they act on a sandstone surface, where the rain falls too seldom to stimulate a vegetation sufficient to make a mould. To this cause is due the dismal desert between Morocco and Timbuctoo; and in the former country the writer has observed the same defective combination of wind and rain acting in an equally unfortunate fashion. It is quite a mistake to suppose that the Sahara is the old dried-up basin of the sea. In reality many parts of it are uplands, much above the level of the Atlantic or the Mediterranean. It is a sandstone formation disintegrated, as Dr. Lenz has shown, by atmospheric influences. Much the same effects are seen when the soil is recklessly denuded of wood. The rainfall, instead of sinking into the ground to appear in the form of springs, runs off the surface, carrying with it the soil also, and covering the valleys with the *débris* of stones and other rubbish. The springs drying up, the rivers shrink in volume, and, as has been demonstrated repeatedly, a once fertile country becomes, subject to sudden floods at one season and at another, in parts at least, little better than a desert. Not to quote more than one instance, out of many, in the province of Choco, south of Panama, there is plenty of forest and sufficient rainfall. In Payta, where there are treeless plains, cultivation has long been extinct and, for a stretch of as much as seventeen years, not a drop of rain has fallen, and the once copious springs that watered the Tuneberg, a range of hills on the east bank of the Rhône, above Strasbourg, have failed since the peasants have hewn down the trees which formerly protected them.

But vegetation on the soil reacts on the land in another manner. The disintegrating forces of Nature are constantly at work, and are rendered beneficent by what may be called the conservative ones. Among the chief of these is the growth of plants. The waves attack and undermine a cliff until it tumbles down and is swept into the sea; again the

* "Peoples of the World," Vol. VI., pp. 243—255, and pp. 275—279, where a full account of this battle between the sea and the land is given.

Fig. 3.—THE GREAT CAÑON OF THE RIVER COLORADO, U.S.A.: 6,200 FEET DEEP.

(After Major Powell, Director U.S. Geological Survey.)

remorseless enemy begins afresh and cuts out the land, until, as is the case in many parts of the English and other coasts, considerable sections of country have disappeared, within historical periods. In time, the devoured rocks are vomited forth by the waves in the shape of sand. If, however, this sand is not kept by a barrier of trees or other plants, or is not bound into an orderly mass by some of the long-rooted—or long-"stoloned"—plants which love such localities, it will blow inland, overwhelm the fertile land, and then the wind comes—owing to the absence of the antipathetic force mentioned—laden with evil to the farmer. Frederick William I. of Prussia cut down a belt of pines between Dantzig and Pillau, with the result that, within a few years, the Haff, a large lake separated from the sea by the ground on which the pines grew, was gradually choked with sand; and the channel by which Elbing communicates with the Baltic at Pillau, and with Königsberg, was threatened. The land has again been planted, but the mischief is partly beyond recall; and the cost of keeping the waterway clear is a great deal more than the two hundred thousand thalers which the thrifty sovereign obtained for the timber. The people of Düben, in the Prussian Province of Saxony, were equally unwise; but, happily for them, they have been able to remedy the mischief they wrought. Having cleared away the forest around their town, the sands which lay to the north-east began to invade the cultivated ground, until many a fair field became a waste, and the cabbage-patches got covered with the common enemy. "Vegetables," writes the historian of this incident, "grew scarce, pasture for cattle rare, and the most serious results were feared, when the forester for the districts offered to arrest the desolating invasion." Nearly sixty years have elapsed since then. "Now rich woods and acacias, birch and pine, wave over the sandy hills, and their fine network of rootlets holds the restless sand in its place, and compels it to quiescence. Every year the citizens of Düben turn out with music and banners—and lager beer, of course—into their woods, and celebrate with much jubilation, and great noise, the salvation of their town." Some districts of Scotland have suffered even more from this forgetfulness of the ceaseless operation of the laws of Nature. In Morayshire, the entire barony of Cawbin has been covered by a wilderness of sand, which advanced steadily at the rate of from three to four, and sometimes, as happens in other regions, at the rate of sixteen feet a year. Ploughed fields, fences, cottages, a manor-house, dovecots, were all irrecoverably submerged, as a Scots Act of William III. expressly mentions, "by sand driven from sandhills; the whole has been mainly occasioned by the pulling up of the roots of bent, juniper, and broom bushes, which did loose and break the surface and scroop of the sandhills." The old kirk of Forvie, in Aberdeenshire, is now a mere ruin, difficult to find amid the sandhills which have overwhelmed the parish. This catastrophe was, in part at least, effected before the year 1688; but probably—in spite of local traditions, which ascribe the work of destruction either to a "curse pronounced upon it by an heiress unjustly dispossessed of her inheritance," or, as a zealous writer of the year 1570 affirms, because "the folks of Forvie were papists and grossly ignorant" (which latter indictment may be admitted)—"the judgment" is due to existing causes continually operating since the establishment of the present coast-line, namely, to the south wind acting on a loosely-bound coast. Now the scene presented is as desolate as any in the

world. For miles the country is as barren as the moving sands of Africa. "No trace of human habitation can be seen; huge hills of driven sand, stretching for miles in every direction, presenting no vestiges of life or vegetation but the bent under our feet, and, it may be, a stray seagull or two over our heads, might have led us to realise the feelings of loneliness which the traveller might be supposed to experience in the vast Desert of Sahara."* The planting of pitch-pine might perhaps here, as in the Landes of Brittany, were the climate only warm enough, not only recover the waste for cultivation, but render it possible to yield, in the shape of tar and turpentine, a better revenue than the crop which, in accordance with the "maidenis malysone," was doomed to flourish there.

Wheels within Wheels.

We have seen from the brief sketch in the preceding pages how tirelessly all the forces of Nature are constantly acting; how at scarcely any moment are the materials of the earth's crust or the organisms which live in or on it at rest; how, in brief, matter circulates in this perfect, but, considering that the process of formation is still going on, never finished world. It has undergone and is undergoing a process of evolution. A surface is no sooner raised than it begins to be depressed. Those "stony rocks," which, to use the expressive language of Linnæus, "are not eternal, but the daughters of Time," are only converted into dry land for the rain, and the rivers, and the winds, and the volcanoes to reconvert into their original elements, and, out of the old materials, to construct a series of fresh strata, which are the same in character if different in composition. But we have also seen how this constant circulation is necessary for the preservation of the equilibrium; how without disintegration there could be no soil, without soil no vegetation, without vegetation no animals which live on plants, and without herbivorous species no carnivorous ones. But when we examine the "wheels within wheels" of this wondrous mechanism of creation, we find that the interdependence of all the forces concerned in keeping up the Globe is even greater than might at first sight be imagined.

What connection there is between the prosperity of the pastoral interest and the number of cats in a district might seem difficult to trace; yet the relationship is not quite so far-fetched as the words might at first seem to indicate. One of the best-known facts in botany is that many species of plants cannot be fertilised without the agency of insects. The bee or other insect flying about from flower to flower in search of food, unconsciously carries the pollen of one plant and deposits it on the stigma of another, thus imitating the physiological act without which the seeds on which the plant depends for its reproduction could not be perfected. Among these plants the red clover is one. Unless the humble-bee can reach it, no seeds will be produced, no other species being able to get at the nectar, and—as the agent in the process of fertilisation does not work for the mere good of the plant—at the pollen which it is destined to carry to the nearest clover flower it alights on. Hence, it is highly probable that, if this species

* The *Aberdeen Magazine* for May, 1832; quoted by Ferguson in *Scottish Geographical Magazine*, 1886, p. 273.

of bee became extinct, the red clover would either become very rare or disappear. Now, as the principal enemy of the humble-bees is the field-mouse, which destroys their combs and nests, but which is itself preyed upon by cats, it is not straining bio-logic to assert, as did Mr. Darwin, that the presence of this quadruped in large numbers determines, through the intervention first of mice and then of bees, the frequency of clover flowers in any particular district. Near villages and towns, the nests of humble-bees are more numerous than elsewhere, owing to the number of cats that destroy the mice. Hence it is fairly deducible from the facts mentioned that the pastoral interests, and inferentially those of man, are largely dependent, first on bees, then on mice, and, last of all, on cats—possibly, we might add, on single ladies with an affection for these feline pets. Until the proper species of bee was introduced into New Zealand the cultivation of clover was found impossible. Elaborate contrivances are noticed in flowers to prevent

Fig. 4.—FERTILISATION OF PLANTS: THE MEADOW SAGE (*Salvia pratensis*).

1, Side view of flower. 2, The same cut down longitudinally; *a*, the calyx or flower-cup; *b*, the curved upper lip; *c*, the under lip, which acts as a platform for the bee to stand on while sucking the nectar; *d*, the young pistil, topped by its stigma; *d'*, the pistil at a later stage; *e*, stamen in its normal position; *e'*, stamen with its anther, shedding its pollen on the back of a honey-bee (*Bombus hortorum*); *f*, position of the proboscis of the bee searching for honey. (*After Dodel-Port.*)

the pollen or "dust" which falls out of the "anthers" reaching the "stigma" of the same plant, insects visiting the flowers in search of honey being the intermediary by which the pollen of one individual is carried to the stigma of another of the same species, "cross-fertilisation" being thus secured. In the meadow sage (Fig. 4) we see, for example, the anthers ripened long before the stigma, so that self-fertilisation is impossible. However, the stamens which at first are high up in the upper lip curve down when they are ripe, so that a bee entering must catch some of the pollen on its back, and then carry it to a flower, where the pistil with its stigma, as it gets ready to receive it, also curves down, and therefore must necessarily come in contact with the pollen-dusted back of the bee. In other plants there are equally remarkable arrangements by which no insect can get at the nectar which cannot repay its meal by aiding in this cross-fertilisation (Fig. 5).

In passing from the tropics to the temperate regions, we observe a falling-off in the number of native plants, owing to the disappearance of those animals necessary for their fertilisation—insects and humming-birds, for example. Roses and pæonies disappear

when the larger forms of the beetle order are no longer to be found. The greater number of *Silenecæ*, and especially the night-flowering species of Catchfly (*Lychnis*) and Campion (*Silene*), find their limits where the nocturnal moths cease. In the Arctic Zone those plants only can be found which are fertilised by the agency of the bee order (*Hymenoptera*), and the order of two-winged insects (*Diptera*), or the wind. This law is illustrated by the flora of Novai Semlai, lying between lats. 76° and 80° N. Out of

Fig. 5.—DEFENCES OF FLOWERS AGAINST UNWELCOME GUESTS. (*After Kerner.*)

1, Transverse section of the root-leaf of *Pinguicula alpina* (the Alpine Butterwort), showing the numerous glandular hairs with which its upper surface is covered. 2, Fragment from the upper surface and central part of the same leaf, showing the two kinds of these glandular hairs, which exude a sticky slime, so tenacious that no small animal that comes in contact with it and once adheres can ever again get free, but is actually digested. 3, Lateral view of the flower of *Circæa alpina*, showing the glandular hairs on the calyx which prevent minute wingless insects getting at the pollen and, being unable to carry it to another flower, waste it. 4, Longitudinal section of the flower of *Epimedium alpinum*, the flower-stalk covered with glandular hairs preventing small animals from creeping up to the flowers, which are rich in nectar and adapted to flying insects, which accordingly visit them and aid in scattering the pollen. 5, Several of the partly-overlapping involucral bracts of *Centaurea Cyanus* (the Corn-flower): lateral view, showing the stiff, sharp teeth round the margin adapted to the same end. 6, Longitudinal section of the flower of *Centranthus ruber*, showing the flower-tube and the spur containing nectar lined with hairs, which, while permitting the insertion of a proboscis, render it quite impossible for any of the smaller insects (*Thrips* alone excepted) to creep in and reach the nectar, while too small to conduce by their visits to cross-fertilisation. 7, Longitudinal flower of *Soldanella alpina*, showing the delicate flaps extending over the nectar pit like a diaphragm to prevent the entrance of flying insects unfitted for its cross-fertilisation. 8, Lateral view of the flower-head of *Centaurea pseudophrygia*, showing spiny protections against cattle or other animals eating off the flower. 9, Longitudinal section of the flower of *Lonicera alpigena*, showing the tangle of hairs which cover in the nectary. 10, A single petal of *Ranunculus glacialis* seen from above, showing the nectar pit covered by a scale-like excrescence, which, combined with a peculiar arrangement of the filaments, prevent any insects not strong enough, either to lift up the obstructing filaments or to push down the scale, from entering. 11, Longitudinal section of the same flower. 12, Transverse section of the upper part of the flower of *Aphyllanthes monspeliensis*, showing a sort of "revolver arrangement" by which only insects that have a proboscis can penetrate to the nectar, those which could not repay their feast by aiding in fertilisation being shut out by the length and narrowness of the passages by which it can be approached.

a hundred and twenty-four species of flowering plants described as constituting the flowering plants of those islands, six belong to the *Pedicularinæ*, which are neither

self-fertilised nor fertilised by the agency of the wind, but entirely by the help of hymenopterous insects. The inference is therefore drawn that, notwithstanding the severity of the climate (the mean temperature of August, the hottest month of the year, not rising above 41° Fahr.), some insects of this class must make these islands their home. One, indeed, is known to exist there. In neither Spitzbergen nor Novai Semlai are there any plants dependent on the butterfly and moth order (*Lepidoptera*) for their fertilisation, though many which are dependent for their multiplication on other species of insects.* It is therefore clear that, as man is dependent for his food either upon plants or upon animals which feed on them, his range and the nature of his culture must largely depend upon the existence of particular insects, which insects, again, are limited less by the conditions of climate than by the absence of the plants on which they subsist, for there is nothing in the climatic vicissitudes of Spitzbergen to admit of various species found there flourishing on its barren soil in preference to others which are so markedly absent. But, even were it otherwise, the fact would equally illustrate the interdependence of Nature, or, as we have described it in homely phrase, of the "wheels within wheels" which exist in every part of the machine.

The currents in the sea, on which depends to so great a degree the comfort of many creatures, and which, next to the winds, are the factors that have aided commerce to take the course which it has taken, are also dependent on the heat of the sun, if we accept the theory usually associated with Dr. Carpenter's name, or, indeed, several other theories of a different school of physics, with the soundness of which we need not for the present concern ourselves. The tropical waters, heated by the blazing sun overhead, expand and rise, while the chilled waters of the North contract and sink. This sets up a steady flow of the equatorial waters north and south to reproduce the surface equilibrium. "But," to use the words of Mr. Charles Morris, "in consequence of this movement, the downward pressure of the ocean waters in the polar regions becomes in excess of that at the equator, and a reverse flow takes place along the bottom to restore the equilibrium of pressure. Thus, through the differential action of the solar heat, there is a steady vertical circulation both in the atmosphere and the ocean. That of the latter is not sufficiently vigorous to indicate itself by a decided surface flow, but its presence has been recently proved by deep-sea thermometrical observations widely extended over the oceans. To it is undoubtedly due much of that special warming of the western coasts of the continents, which was formerly ascribed to the influence of the Gulf Stream and other great surface currents." The surface currents—the "rivers of the ocean," as they have not inaptly been termed—are due to various causes, with which this is not the place to concern ourselves, but it is now very generally held that the equatorial currents owe their set to the trade winds, whose "steady push" on the surface of the tropical waters keeps them in continuous motion westerly round the world. How long it took before the inertia of the water was

* Trautvetter's "Conspectus Floræ insularum Nowaja-Semlja" in *Trudvei Imperatorskagi S. Petersburgs-Kago Botanicheskagi Sada*, Vol. I., pp. 43–88; Spörer's "Nowaja Semlä" (Petermann's *Geographische Mittheilungen*, Ergänzungshefte, No. 21); Warming's "Biologiske Optegnelser om grönlandske Planter" (*Botaniske Tidsskrift*, Vol. XV., pp. 151–206); etc.

overcome by the force of the wind, in order to produce a steady current, may be conjectured. According to an ingenious German physicist,—Dr. Zöppritz—thousands of years must have elapsed. But these currents of the ocean, though thus possibly due to the currents of the air, are influenced in their direction and consequences by the masses of land which they encounter. If the currents produced by the trade winds did not encounter land in the tropical zone they would flow round the earth in this zone, without any deflection north or south; but owing to the Northern hemisphere having the greatest amount of land masses, and the southern hemisphere the greatest amount of water, the result is that the trade winds, and with them the currents, are deflected towards the North, owing to the corresponding difference of the heat distribution. It is, however, to the merest tyro in geography a popular delusion to imagine that the "winds blow whither they list." A hundred proverbs have consecrated this error, and from Lapland to New Zealand "a boy's will is the wind's will." In truth, no class of atmospheric phenomena are more under the influence of circumstances over which they can exercise no control. In the North, according to the changeableness of our temperature, the winds are seemingly irregular; in the Tropics they are to be reckoned on with the utmost confidence, and are subject to much the same laws as the sea's surface, which they deflect into rivers circling over the ocean. In many respects it will be found, when we come to consider their cause and operation, they follow much the same laws as do the marine currents. In the Tropics the air expands, and rises and flows towards the poles in the upper reaches of the atmosphere, descends to the surface in the temperate zones, "and thence partly returning to the equator, partly continues to flow towards the poles. These air currents, deflected by the rotating movement of the Earth, become the easterly trade winds in the Tropics, and the westerly anti-trade-winds in the North and South temperate zones. They are greatly disturbed, particularly in the Northern hemisphere, by the influences of the land surface, which acts to produce monsoons, or steady winds, to and from the centre of the continents. In the Southern hemisphere they are more persistent, and particularly in the South temperate zone, where a broad expanse of ocean permits the westerly winds to blow steadily and strongly throughout the year."

In the very depths of the ocean, contrary to the belief which was at one time entertained, the influence of the sun is in its way as great as on dry land. Life exists at the depth of at least five miles, and the ofttimes gay colours of the animals brought up from the fathomed "caves of ocean" prove that some ray of the sun must have reached them. Again, the making of some men's homes is directly dependent on the temperature of the ocean. The coral polyp—which rears so many of the Polynesian Islands by a slow system of adding patch after patch of lime, eliminated from the water in which it lives to the tube in which it is housed—is strictly limited to certain depths. It cannot live very far below the surface, nor, we shall see, can it exist when the warmth of the sun reaches a certain specified heat.

Yet the circulation of matter does not stop here. Hot springs—that is to say, the rainfall which has sunk into the soil, and come in contact with the hot places in the interior of the globe—worm their way through the bowels of the earth, dissolving out whatever is soluble and then discharging it on the surface, where, after cooling,

it forms vast masses of flinty and other materials of the crust, such as those which we find in the Yellowstone country in North America, and in the Lake District of New Zealand (Fig. 6, Plate II.). The latter region, which is situated in the old Province of Auckland, was—and is still—one of the most remarkable "show places" of the Northern Island of New Zealand. The "Hot Lake District" is a land of geysers, boiling mud baths, and sulphur springs of such efficacy in rheumatic and cutaneous diseases that it is commonly regarded as the Bethesda of the Antipodes. But of all the marvellous spots in this wonder-land of the South, the pink and white terraces of Rotomahana were the most extraordinary. These beautiful objects consisted of a graduated series of basins lined with flinty matter, smooth as polished marble, and formed in the course of ages by the silicious solution deposited from the Rotomahana hot springs. They were arranged in the fashion of steps, and the water flowed in a perpetual cascade from one to the other, gradually cooling in the course of the descent. The result was a series of natural baths, with the water ranging in temperature from lukewarm in the bottom basin to boiling-point in the one where it took its rise. The basins were filled with exquisitely blue water, and edged with a delicate fringe of sparkling stalactites, the whole forming an effect of Nature quite unique, and lovely beyond the power of pen to describe or pencil to portray. The entire country for a distance of 120 miles from north to south, and about twenty in breadth, is hot and crumbling, and at places the crust is so thin that unless the pedestrian treads warily he will get immersed in boiling mud. But though volcanic eruptions had not been infrequent, it was the general opinion of geologists, up to the 10th of June, 1886, that the Lake District was the scene of waning volcanic energy, and that as time rolled on its activity would grow less and less, until at length even its geysers would become things of the past. But on the day in question the world was rudely undeceived. About midnight, after a succession of earthquakes, Mount Tarawera, a dormant volcano, burst into violent activity, and was followed by the entire Paeroa Range, including even Ruapehu, which had been extinct from a period beyond which the legends of tradition extended not. This catastrophe we shall describe more fully when we come to consider volcanoes and their phenomena. But what immediately concerns us as physical geographers is, that amid the havoc which ensued, and the lives which were lost, the pink and white terraces of Rotomahana disappeared, destroyed by the forces which in their quieter moods had reared them, though doubtless, in the ceaseless changes which are for ever going on, the silicious springs will continue dissolving out the flinty matter, bringing it to the surface, and again depositing it in pearly cascades, more lovely, perhaps, than those which are now only a memory of the past. However, as if to demonstrate that every particle of matter is undergoing a constant revolution, we learn in a private letter from the shaken district that, in less than a fortnight after the volcanic showers had ceased, the sorely-tried earth hastened to seek what advantage it could in the cataclysm. A deluge of rain speedily washed away almost all traces of the volcanic dust which was deposited in the neighbourhood, and did much good. "There is no doubt whatever that the dust contains (as most volcanic soil does) valuable fertilising properties. It has been found by analysis that it holds about three-tenths per cent. of potash, lime, and soda, and the quantity deposited here having been about sixty tons

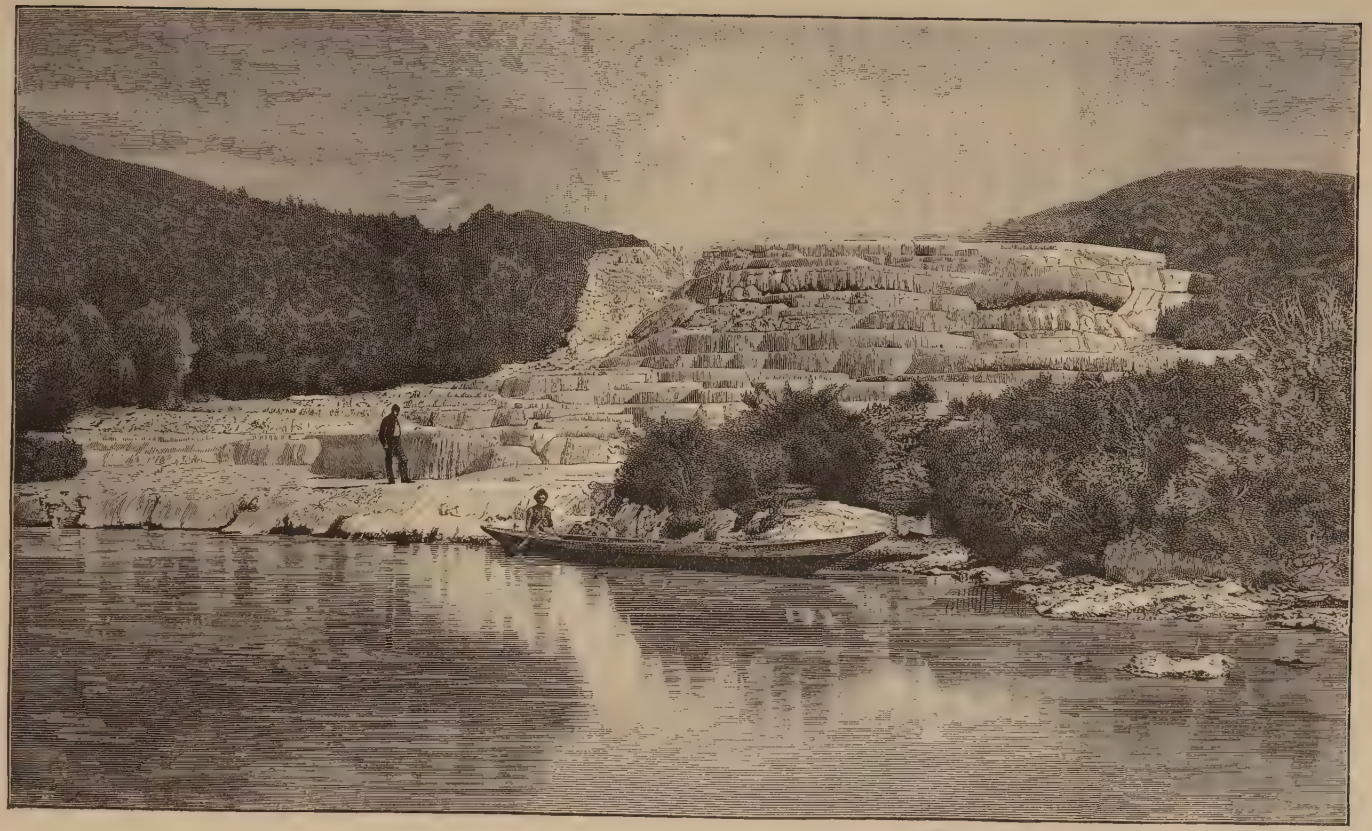


Fig. 6.—THE ROTOMAHANA WHITE TERRACES AND HOT SPRINGS, NEW ZEALAND.
DESTROYED BY AN EARTHQUAKE ON JUNE 10, 1886.

(After a Photograph.)

per acre, it follows that the land has received a top dressing of about three and a half hundredweights of the above valuable constituents, and there is nothing deleterious in the remainder. Indeed, it does not require the analyst to convince one of the benefit the land has derived, as one can see it by the wonderful growth of the grass and clover, and other more delicate plants, even in an exceptionally cold season. Of course, there has been great loss by moving and feeding stock while the pasture was covered by the dust, but in my opinion and that of practical farmers here a great permanent benefit has accrued to all the land in the district, excepting, of course, that in the immediate neighbourhood of the eruptions, where the country is hopelessly buried in mud and dust." Thus the circulation of matter is incessant.

The sun is, therefore—apart from the influence which it exercises as the controller of the "solar system,"—the ruler and the life-giver of the universe, the provider of the rain and the wind and the warmth, and all that rain and wind and warmth can supply. Hence, from the physical geographer's point of view, there is more in astrology than the puerilities of the astrologers ever imagined. When Cassius declares that "the fault, dear Brutus, is not in our stars, but in ourselves, that we are underlings," he gives forth a sound protest against the jargon of the soothsayers, who cast horoscopes and determined the fate of man by the "conjunction" of the planets. But meteorologists, and a great many people who are not meteorologists, know how a bright sky or an east wind affects their mental and material constitution, and thereby their daily life, or it may be their future career. The cold of the North does not chill the heart, but the torrid sun of the South imparts a pepperiness, almost a ferocity, to the hot blood of these regions. On a cold day a man feels better disposed towards the world in general than on a hot one, and the irritability produced by the hot wind which at times sweeps over the plains of La Mancha and Andalusia is so little provocative of kindly feelings that no proverb is more frequently heard in Cadiz or Seville than "Ask no favour during the Solano." The mental and physical robustness felt in a temperate climate is of course familiar to every one in contradistinction to the lassitude which sooner or later creeps over every resident in warm countries, where during the heat of the day a *siesta* becomes so imperative that in one of the revolts in Madrid, insurgents and troops alike, by a well-understood arrangement, abated hostilities for a couple of hours, near the dinner-hour, and resumed the offensive as soon as the period of quiescence had passed. The vigour of the Northern nations, their enterprise and their versatility, are in no small degree due to the vicissitudes of their climate. The man who never knows what to-morrow may bring forth requires to be far-seeing, energetic, and provident. But the toiler who is certain that when the rain stops there will be "none to speak of" for the next four months, is apt to grow indifferent, to take the world too easily, and to spare himself needless thought for the future, until his sluggish brain refuses to act when there is most need of its being ready for work. On the other hand, the people of a land subject to the terrible disasters of earthquakes, tornadoes, and volcanic eruptions, are likely to become nerveless, and in time to get impregnated with that hopeless fatalism which is embodied in the adage anent "what must be, will be," or which is the antipodes of that cheerful philosophy

regarding Providence helping those who help themselves. Buckle, indeed, amid many other generalisations—which if not *vero* were at least *ben trovato*—attributed much of the superstition which envelops the Spaniards, Italians, and Portuguese, to the physical horrors amid which they and their ancestors live and have lived. The imagination is strong in their lands, but the reasoning faculty is weak. Science scarcely asserts itself, and the philosophers of the Peninsula have never exercised much influence over European thought or progress.* It is, therefore, quite within the limits of truth to affirm that in some respects the planets and the atmospheric and terrestrial environments of man re-act on his physical, mental, and moral character.

Man and His Surroundings.

But the distribution of man is dependent upon the distributions of the animals and plants on which he subsists; so that he, like the rest of creation, is intimately bound up with heat and light, the winds and the rain, and therefore with the "stars that move in their courses." He is also, to some degree, a creature of the ocean currents. Islands have before now been peopled by wandering canoemen, who have been carried by the currents out of their courses; and the Japanese junks which have at different times been wrecked on the north-west coast of America would go far to explain how that continent might have been peopled, were not the hypothesis of its having obtained the original stock from whom the present race of "Indians" are sprung, from Asia, by way of the comparatively narrow Behring Strait, still more easily accepted. Again, were it not for the currents conveying fruits and trees—in the roots of which seeds and, it may be, dormant land molluscs and the eggs of other animals are buried—many coral islands now thickly peopled would have remained lifeless, uninhabited, and unfitted for the abode of man.

The influence of certain species of plants, and inferentially the character of certain regions, on civilisation, has been often discussed, and, before we have finished our task, may be rehearsed once more. For example, the dense forests of Brazil have not admitted of the savages who roam through its jungles or paddle along its vast rivers ever rising much out of the rudest hunter stage of existence. But in the cool uplands of Peru and Mexico, in a region fitted for the growth of the beneficent maize, a comparatively high grade of civilisation was attained. The dense forests of the western slope of the Rocky Mountains, and particularly of the region between the Pacific and the Cascade Range, with endless facilities for obtaining abundant supplies of food in the rivers and other waters, have been equally unpropitious to advancement in culture, most of the tribes inhabiting the region being in the rudest state of savagedom, though not unskilful in the fabrication of their fishing implements and, in the case of the Hydahs of Queen Charlotte Islands and the neighbouring mainland, endowed with a considerable amount

* This theory is ingeniously worked out, as all Buckle's ideas are, without much regard to the influences of race on mental traits, in the "History of Civilisation in England," Vol. I. (Ed. 1882), pp. 122, 123, 126, 375, 376, etc.

of artistic ability. In the region formed by the wide prairies of Central North America the buffalo hunters are—or were, for the bison has all but vanished—little better, so far as civilisation is concerned: though, requiring to exercise their limbs more freely in order to obtain food, they are as a rule of finer build, though, if possible, of worse morals. But when the Europeans first reached Eastern America, they found the tribes there, though barbarian, not without the germs of a higher life. For they were stationary; they were therefore imbued with the love of country; and having for ages cultivated the maize, they had experienced the humanising influences of agriculture; and therefore, if ruthless to their foes, capable on occasions—unless all history be lies—of acts of great magnanimity to the whites, who did not always deserve much consideration at their hands. The people of the Southern Continent, owing to their isolation from those of the other parts of the world, have been noted as more deficient in culture than those of the North, who, from their geographical position, are better able to communicate with each other, and profit by whatever race has to teach to race.

That the physical configuration of countries has changed or controlled the course of history is familiar to the least observant. England and the English owe many of their salient characteristics to their insular position; while the geological features of our island have impressed the people of particular districts with features likely to be more lasting than the rapidly-vanishing traits of race. Mr. Freeman has shown how Europe, the continent most abounding in peninsulas, is occupied by nations, which in their turn—Greeks, Romans, Spaniards, Portuguese, Scandinavians, and, if we regard the British Islands as a dissevered peninsula of France, English—have been important agents in the civilisation and colonisation of the rest of the world. Then, after the ancient empires had fallen in pieces, Germany, from its central position, exercised a similar controlling influence, though, being an inland country, it has not at any time been a colonising power; and though vast numbers of Germans leave their country for other lands, there is little likelihood of the course of history being reversed by the recent feeble efforts in that direction. The peninsulas, moreover, being cut off in a marked manner from the rest of Europe, developed a civilisation in each case peculiarly their own. "No doubt," the eminent historian mentioned remarked, "the history of each country has been largely influenced by the disposition of the people who settled in it, and by what is called national character." But then the geographical position itself has influenced the disposition of a race which claims such a region for its home, by giving it a better or a worse field for working it out. Thus, as has been well said, neither the Greeks in any other country, nor any other people in Greece, could have been what the Greeks in Greece really were. "The nature of the country, and the nature of the people, helped one another, and caused Greece to become all that it was in the early times of Europe."

It is a matter of familiar observation that a people nurtured in a flat land, if not more heroic—the Dutch are in proof—than the inhabitants of mountains, are more prosaic, in brief, more in keeping with their surroundings; though, again, as mountains are invariably the refuge of a race too proud to submit to the conqueror's yoke, or too weak to resist him, the rule may work conversely. The stronger tribes in any

country are always found to occupy the sea-coast or the plains. This we see in the Papuan Islands, which the Malays have taken possession of; and in Morocco and Algeria, the Berbers, the original inhabitants of the country, inhabit the uplands, while the conquering Arabs roam in the plains below. The pure Celts of England keep their ancient tongue among the hills of Wales; and their brethren have in Scotland been driven up from the flat plains of the south to the highlands of the north. Again, the Swiss are the French, German, and Italian peoples who have made it convenient to escape the despotism of powerful sovereigns by taking refuge in the more inaccessible Alpine valleys. A slight study of the distribution of races in Switzerland, with a map of the mountains before us, brings out very clearly some of the facts we have been trying to inculcate, as to the influence of physical features upon settlement and civilisation. Northern races, that is to say, the Germans and Celts, occupy the north; and the southern, or Latin-speaking, people, that is the Italian and French stocks, in like manner hold nearly all of the south. But when we examine the Rhône valley, we find that up to Sion it is Celtic; at Sierre it is mixed; and higher up the stream it is wholly Teutonic. The valley of the Rhône is long and narrow. Beyond the passage of the Villeneuve, France has only passage into it—"the high and lateral entry" from Chamounix—by the Forclaz. Through these two gorges the Gauls from Burgundy and Savoy poured into the Valais; but in pouring up the river they were met in front and taken on the flank by Teutons coming by the Furka pass from Andermatt, by the Grimsel pass from Meyringen, by the Gemmi pass from Unterseen, by the Col du Rawyl from Thun, and by the Sanetsch pass from Gsteig and Saanen. Faced by their rivals they retired on Sion, and there have ever since held the ground.

Again, taking the Rhine up to Chur, the river is German; in Ilanz it is mixed: and higher up the stream is Rhæto-Romance. The reason is that, though Nature has given the Teuton five inlets to the Rhône, it has denied him access to a river which he considers peculiarly his own. From Ober Alp to Trons in the Fore Rhine valley there is not a track whereby even a chamois could cross the northern heights. From Trons and Flims there are two narrow paths; near Ilanz an opening enables the Panix to be reached, though both paths are hard to climb; while, on the southern bank, a dozen easy roads make access to the Italian valleys easy. Thus, "a countermarch to what has given the upper waters of the Rhône to men of northern race, has given the upper waters of the Rhine to men of southern race. A Teutonic colony has pushed towards Italy; and if they have not crossed the ridge, their colonists hold the mountains to the top. They hold the hamlets of the Rheinwald and the pastures of Averserthal. Some German thorps are circled by a foreign population, like German colonies in Russia. One such thorp is that of Bosco, in Ticino. St. Martin and Obersaxen are Teutonic thorps."*

Geographical features have, therefore, an important influence on civilisation. They check or expedite settlement. Industries are necessarily dependent on the soil and the

* Dixon: "The Switzers," pp. 59-61; "Peoples of the World," Vol. V., p. 318, and Vol. VI., pp. 126-128, 138-139.

climate, and the character of every people is more or less influenced by the craft which they follow. In this way, a geological formation, or a mountain ridge, or the fact of a river being a little swifter or a little deeper, being unpicturesquely smooth or impeded by cataracts and falls, may turn the march of armies and mould the course of history.

But, if man has been curbed by his inanimate surroundings, he, as the most powerful of all organised beings, and, in individuals, perhaps the most numerous of the higher animals, is rapidly reversing the process. He has changed the entire aspect of vast continents; he has hewn down primeval forests and converted their sites into corn-fields. To graze his flocks and herds he has exterminated the wild animals which from time immemorial pastured the prairies; and, in several instances, in order to gratify his appetite, he has decreed or is decreeing the death of several gigantic mammals and large birds, which until he burst in upon their haunts, were plentiful. Within less than a century, man has drained lakes and joined seas; in the course of his history he has turned gardens into deserts, and made the desert bloom with verdure; he has covered the sites of wigwams with great cities; and again, by his ferocity, has so thoroughly erased what were for ages the wonders of Pagandom, that it is all but impossible for Christendom to trace the places where once upon a time teeming towns had for ages hummed with life.

We thus see that every part of Nature is connected with every other part; that it is impossible to detach any portion without marring what remains; and that therefore it is difficult to gain anything like a satisfactory view of this marvellous harmony if little detached sections are chosen for study. We may not be able to probe it very deeply or to analyse it exhaustively, but it is necessary to take it as a whole. We have also seen that the earth is, almost without hyperbole, a sentient being. Everything is more or less in motion. Nothing is lost, yet nothing is ever at a standstill. Even the minute shells—so minute that, without the aid of a microscope, they cannot be seen—which absorb the dissolved lime from the sea-water fall to the bottom after the frail specks of living jelly to which they afforded a home have run their course, and are utilised by thrifty Nature to make chalk; while the decomposition of the shells of fresh-water molluscs gradually accumulates marl beds, which, spread upon the soil, impart fertility to the impoverished earth, and thus indirectly help to feed man and beast.

This continual movement of the winds and waves, this wearing down and raising up, this vomiting forth of volcanic matter, this disruption of the solid rocks by sudden shocks, have been going on from the beginning of time. In the earth's crust we have ample proofs of this constancy of the forces of Nature. The rocks, indeed, contain almost no record which cannot be duplicated in modern times. No new laws have been called into action. The remains of the plants and the animals which they contain are different, in the vast majority of instances, from those now living on the earth; but it will be our business to learn, before we go very far on our road together, that these "fossil" forms are modelled on the same plan as the "recent" ones, and that in not a few cases regions which are in our day characterised by some peculiar faunas were, in the later geological ages, characterised by larger types of the same birds and mammals. The laws of Nature have been eternal, though their operations have been tardy. But, if the "mills of God grind slowly," they "grind exceedingly small."

CHAPTER I.

Land and Water: their Proportions and Relations.

Shape of the Earth—Relations of Land and Water—The Continents—The Seas—The Islands—The Mean Height of Continents—The Volume in Bulk of Continents—The Bottom of the Sea—Vertical Elevation of the Land Masses—Table-Lands—Isolated Rocks—Mountain Shapes.

At a later stage of our studies we shall have occasion to investigate the data from which the shape of the Earth has been ascertained. Meanwhile, before entering on the discussion of a point so abstruse, it is more instructive to examine facts which lie more patent to our observation. However, even at this early period it may be well to remind the reader that the so-called globe is really a sphere, flattened at each end, and measuring, if a hole could be bored from the North to the South Pole, 7,899·114 miles, and from one side of the equator to the other 7,925·604 miles. Even then the sphere is not quite symmetrical, the equatorial circumference being an "ellipse" instead of a circle, so that the greatest axis of the equator lies in a meridian which, if extended, would pass through Ireland, Portugal, and the north-west corner of Africa, and cutting off the north-east corner of Asia in the opposite hemisphere.* But of this *lithosphere*, or stony crust of the earth, about one-third part is composed of hard or rocky masses, in contradistinction to the gaseous atmospheric, or liquid portion, sometimes known as the *hydrosphere*. This hard portion is suspended in an atmosphere of air and of water externally, and is internally—wholly or in part—a fiery mass, the covering of which we term the *crust of the earth*. It is impossible to define with much exactitude the density of this lithosphere. We can merely ascertain the approximate character of the projecting rocks; and even then it is seldom that we can examine them in their greatest depths. However, judging from the data thus ascertained, the density of the earth's crust is about two and a half times that of water, while the mean density is more than twice as great, or about five and a half times that of water. A glance at a map will show that only a proportionately small part of the lithosphere rises into elevated masses. Traversing, as it were, more or less extensive masses of water, the different portions of the land which appear above the surface are connected by small isthmuses or necks of land. The largest of these land masses are termed *continents*, and the waters which divide them *seas*. The continents represent the elevated and the seas the depressed parts of the earth's crust. These variations of level are, in all probability, due to a contraction of the crust in consequence of the diminution of heat at the centre of the earth, or of the cooling of the globe from a condition of high temperature. The present form and size of the continents and seas are not primeval. They have been gradually evolved, and, as we have already seen (pp. 7, 8), the shape of the earth is still being more or less affected by forces which have been in action from time immemorial. These successive and manifold changes, and the action of different geological agencies, have greatly transformed the contour of the continents. It is thus clear that, as the surface of the Earth is undergoing a gradual process of change, our most trustworthy maps can only be regarded by the geologist as presenting to us a picture of the world which is destined to become untrue in course of time. Indeed, so constant are the alterations which the surface is undergoing, that, even were it possible to have an exact model of the earth instantaneously constructed, it would, were not the forces of Nature suddenly brought to a standstill, be more or less false within the next hour.

* Clarke: *Philosophical Magazine*, August, 1878.

Relations of Land and Water.

Modern exploration has curbed the imagination. With the exception of a considerable expanse in the Polar basins, very little of the world is now unknown, so far at least as its outlines are concerned. Accordingly, though it will be long before the contour of the surface is perfectly portrayed, we are enabled to arrive at some approximate idea regarding the size of the seas and the territories which, as it were, are immersed in them. According to the last estimates, the area of the entire globe is 148,179,808 square miles.* If the continents and islands, with the partially unexplored North and South Polar regions, are taken as occupying 39,534,448 square miles; this leaves a space of 108,645,360 square miles for the seas. Thus the proportion of land to sea is as 1 to 2·7; or if the surface of the earth is taken as 1, then the land covers 0·266 and the sea 0·734 parts of the globe. In other words, about three-quarters of the surface of the world are occupied by ocean, and little more than a quarter is above the water; or if we take the entire superficial area of the globe—as Krümmel and Wagner have done—at 197 millions of square statute miles; 145 millions of these are covered by sea, and only 52 millions occupied by land.† The land and the water are, however, very unequally distributed. The largest space of land is in the Northern, and the most extensive expanse of water in the

Fig. 7.—DIAGRAM SHOWING DIVERGENCE OF LAND MASSES AND ZONE OF CLEAVAGE OF THE EARTH.

* Here, and elsewhere, when the contrary is not expressly stated, geographical or nautical miles—of which there are sixty to a degree—are to be understood. One geographical mile is equal to 1·86 kilomètres, 0·24 Austrian mile, 0·25 German mile, 0·33 nautical league, 0·42 French league, 1·74 Russian werst, and 1·15 English statute mile. In ordinary parlance—and hence in most English works on political geography—the area of countries is usually given in English statute miles, which makes the amount appear considerably larger. Thus, while Holland contains 643 German square miles, or 10,288 geographical miles, in the school text-books it is credited with 13,670 statute miles. But in a work on physical geography it is essential, when dealing with scientific details, to employ a uniform scientific measurement.

† The exact figures are 144,386,354 square statute miles of water, and 53,517,373 square miles of land. But as Penck shows, the estimate is made on the basis that the Polar regions are altogether composed of water, and that in reality the amount of land and sea is, owing to various circumstances, variable. The figures given must, therefore, be taken as only approximate (*Mittheilungen der K. K. Geographische Gesellschaft in Wien*, Vol. XXIX.). (1886.)

Fig. 8.—PORTION OF THE ICE-WALL AROUND THE SOUTH POLE, IN LAT. 78° 15′ SOUTH.

(After Sir James Clark Ross.)

Southern, hemisphere. In the Northern part of the world the surface of the land is 0·40, while in the Southern portion it amounts to only 0·13. The latter has, therefore, scarcely one-third as much as the first, and its surface of water is in proportion to that in the North as 10 to 7. If, therefore, we were to divide the Earth into two hemispheres, one composed of the greatest amount of land, and the other of the greatest amount of water, we must make the division, not perpendicularly to its axis of rotation, but perpendicularly to a radius which traverses the western part of the British Channel. The North-Eastern hemisphere is here opposite the South-Western hemisphere; London and Paris would fall about the centre of the first, and the antipodean islands of New Zealand would form the central lands of the other. Thus one of these hemispheres is therefore a vast area of lands; the other an equally extensive expanse of waters. These facts were not readily accepted. For a long time it was regarded as certain that if the North was covered with continents, the South must be equally well provided, otherwise the balance would not be kept true. When New Zealand was discovered it was considered to give a basis for this belief. But when Cook returned from his great voyages, without finding any such Southern continent, the theory had to be abandoned and, as the amount of land which can lie within the wall of ice which bars the way to the South Pole (Fig. 8) must be very limited, is never likely to be revived.

The Continents.—It is customary, more for convenience of description than for any other sounder reason, to designate five continents. These are as follow :—

Europe	2,850,400	square miles.
Asia	13,039,920	,, ,,
Australasia and Polynesia *	2,577,728	,, ,,
Africa	8,696,120	,, ,,
America	11,901,104	,, ,,
	39,065,272†	,, ,,

* Or Oceania, as it is not inaptly designated.

† Behm : "Geographische Jahrbuch," Vol. I. p. 128. For a somewhat higher estimate, see Murray : *Scottish Geographical Magazine*, Vol. II. p. 548.

In addition to these five continents, there are the unexplored North and South Polar regions, so that, if a liberal estimate of the amount of land in these hitherto inaccessible regions is made, the entire area of the continents may be put down at 39,534,448 square miles.

The masses of land might also be considered as two large continents: an eastern, including Europe, Africa, Asia, and Australia, and a western, composed of North and South America; or three double continents: Austral-Asia (because Australia is nearly united with India through the East Indian Archipelagos), Europe-Africa, and North and South America. These three pairs appear, so far as the northern halves of the two eastern pairs are concerned, subdivided in the same way by seas. Asia and Europe, moreover, forming really one continent—the latter being a peninsula of the former—might be termed Eurasia. Otherwise Europe and Asia have natural border zones in their great inland salt seas—the Caspian and the sea of Aral. These sheets of water, also, indicate extensive continental depressions, the surface of the Caspian lying 84 feet ‡ below that of the Black Sea, which may be regarded as not differing much from the average oceanic level. In these estimates the character of the Polar Regions has been little more than guessed at; especially is this true of the Antarctic Basin. But every fact is in favour of the belief that there is a very large mass of land at the South Pole.

The Seas.—Just as we have five continents, so we have five oceans, which are in communication with each other :—§

The Pacific Ocean ...	46,819,360	square miles,
The Atlantic Ocean ...	23,165,120	,, ,,
The Indian Ocean	21,306,800	,, ,,
The Antarctic Ocean ...	5,950,368	,, ,,
The Arctic Ocean	4,443,616	,, ,,
	101,685,264	,, ,,

‡ In the pages which follow, English feet, unless when the contrary is expressly stated, must be understood. A mètre is 3·28 English feet, 0·513 toise, and 3·08 French or Paris feet.

§ Otto Krümmel : "Versuch einer vergleichenden Morphologie der Meeresraüme" (1879).

To these may be added the smaller seas of the more territorial type, such as the Mediterranean, the Baltic, the Gulf of Mexico, the sea around the Bahamas, the Caribbean Sea, the Austral-Asiatic, the Persian Gulf, and the Red Sea, which conjointly amount to 4,887,216 square miles; and what may be called the border seas,* namely, the German Ocean (North Sea), the English Channel, the Irish Sea, the Gulf of St. Lawrence, the Sea of Okhotsk, the Japanese Sea, and the Eastern Chinese Sea, in all 2,120,302 square miles; so that the total area of the known sea, which covers so large a portion of the earth is, in more exact figures than those which may be accepted when we have to roughly calculate the proportion of land to water, 108,692,862 square miles. Indeed, so extensive are the seas that the Pacific Ocean alone occupies a larger space than all the continents put together.

Efforts have been made to define a certain law in the arrangement and grouping of the basins of the seas. A law, if such is the proper name for it, appears plainly before us in the convergence of the masses of land towards the North and their divergence towards the South. In the land hemisphere (Fig. 7) the four continents which appear are massive and broad towards the North, but tapering into capes, which give them a wedge-like form, towards the South. Otherwise there are wide differences between them. Europe and Asia are deeply indented by arms of the sea and bays, which form numerous promontories and capes, nearly all of the latter, like the great continents, pointing towards the South.

Africa, on the other hand, is distinguished by a remarkably even coast-line; it has not a single break in its long shore, comparable with the many in Europe and Asia. America is in its northern part not unlike Europe and Asia, in the fact that its shores are indented by deep bays and fjords; but South America—except in the extreme southern parts—and Australia have a general likeness to Africa, in their comparatively unbroken coast-line. Francis Bacon was the first writer who remarked that the southern extremities of the two worlds terminate in narrow points turned towards the Southern Ocean, while their northern portion widens out so unexpectedly that the early navigators, reasoning from the analogy presented by Cape Horn and the Cape of Good Hope, were grievously disappointed when they failed to double the North by means of the supposed North-east and North-west Passages, as easily as they had done the South. But it was Reinhold Forster, who accompanied Cook on his second voyage, who expanded this observation by pointing out other analogies and coincidences, which had not until then been noticed. He called attention, for example, to the fact that the southern parts of all the continents are high and rocky, and "seem to be the extremities of mountain belts, which come from the interior and break off abruptly without transition at the shore of the ocean. Thus America, which terminates in the rocky precipice of Cape Horn, the last representative of the already broken chain of the Andes; thus Africa at the Cape of Good Hope, with its high plateau and its table-mountain, which rises from the bosom of the ocean to a height of more than 4,000 feet; thus Asia, in the peninsula of Hindostan, sends out the Ghauts to form the high rocks of Cape Comorin; and lastly Australia, whose southern extremity presents, at South Cape in Van Dieman's Land, the same abrupt and massive nature."† Again, all the continents have islands or other fragments of land east of their southern points. Thus, for example, the Falklands lie to the south-east of South America, Madagascar and the volcanic islands in its vicinity to the south-east of Africa, the East-Indian Archipelago to the south-east of Asia, and the West Indies to the south-east of North America. To these examples might be added —Ceylon, Australia, and New Zealand, which lie more or less off the eastern extremity of Asia. A third peculiarity which Forster pointed out was that the continents have a

* That is, they properly belong to the nearest continent, since a slight elevation of the bottom would convert them into dry land continuous with that which they border.

† Guyot: "The Earth and Man," p. 14.

deep bend on their western side towards the interior. "On this side their flanks are as if hollowed into a vast gulf. In America the concave summit of this inflection is indicated by the position of Arica, at the foot of the high Cordillera of Bolivia. In Africa the Gulf of Guinea expresses more strongly still this characteristic feature. It is more feebly marked in Asia by the Gulf of Cambay and the Indo-Persian Sea; it appears fully in Australia, where the Gulf of Nuyts, or the Great Australian Bight, occupies almost the whole southern side."

How these peculiarities—or, if the reader pleases, coincidences—are explained we shall presently inquire. But before doing so we may remark that the three northern continents lie closely together around the North Pole, and their greatest masses come within the temperate zone. The three Southern landmarks are, on the contrary, divided by great seas, and lie therefore far apart from each, for the most part inside the torrid zone. The latitude 45° forms the mean southern border of the continents, and this is exactly midway between the equator and the South Pole. Between the northern and the southern continents there is a zone of cleavage visible in an east-westerly direction (Fig. 7). Inside this zone of cleavage lie the Archipelagos of the East and West Indian Islands, and the Peninsulas of Southern Asia and Europe. The Red Sea and the Mediterranean, and the Western Indian Ocean, with their bordering seas, form here almost uninterrupted water-communication around the globe; and the Suez Canal having been finished, it now only requires the construction of the Panama Canal to complete the circuit. The largest extension of the eastern continent, from west to south, is 10,350 miles—nearly three times the size of the western one. This inequality in the extent of both continents is to be sought for in the inequality of the Pacific and Atlantic oceans. The former has a breadth of 6,000 miles, while the latter is only 2,800 miles broad. Thus a broad and a narrow continent, and a wide and a narrow sea-basin, are in juxtaposition. The northern continents, it may also be remarked, are of a more definite geological structure, and their plants and animals are more familiar, while their

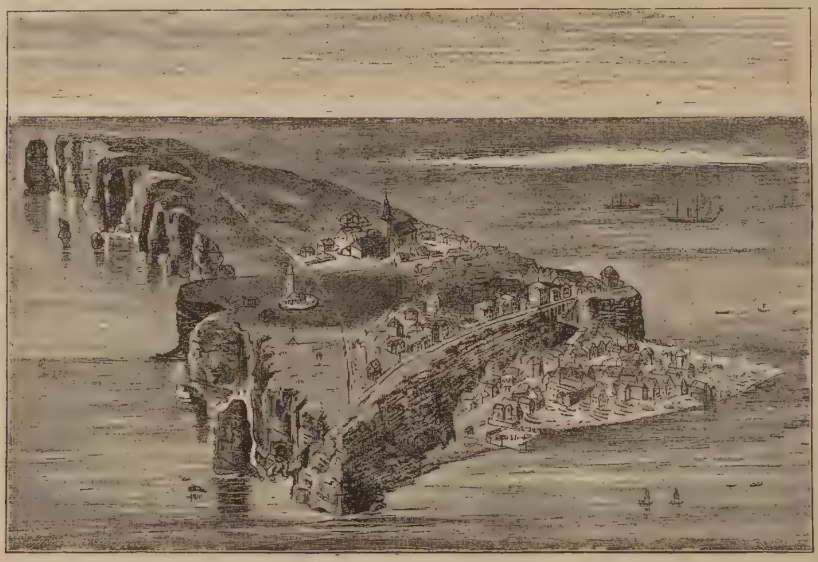


Fig. 9.—HELIGOLAND (EXAMPLE OF CONTINENTAL ISLAND).

contour has largely determined the history of the world.

The southern are enclosed by their principal range of mountains on the eastern and western shores, and exhibit large depressions in the centre, and bear distinct evidences of the transformations they have undergone. At their southern extremities are living the last remnants of the most ancient races of mankind; the Pescharais, or Tierra del Fuegians, at the southern points of America, the Hottentots at the southern points of Africa, and the Australian aborigines at the southern points of Austral-Asia. Moreover, the plants and animals found in these regions are also, for the most part, of a type which flourished in long past periods of the earth's history. Still these facts — since facts they are, no matter what theory we may deduce from them —do not explain the curious shape of continents already mentioned (p. 27). Forster, however, was ready to seek the cause of the features, which he was the first to point out, in a great "cataclysm, or inundation coming from the south-west. The waters of the Southern ocean dashing with violence against the barrier which the continents offered to them, ground away their sides, scooped out the deep gulf opened towards the south-west, swept off all the movable earth from the southern side, and left nothing standing but their rocky points, which were only the skeleton. The islands on the east would be only the accumulated ruins of this great catastrophe, or the fragments of the continent protected from total destruction by the jutting point which received the first shock." This theory is too sweeping, too little in accordance with the doctrines which geology holds, to be accepted in modern times. Nowadays, we are sceptical over cataclysms and catastrophes of this kind, and are inclined to attribute the endless changes which the earth has undergone to the quieter, less spasmodic

Fig. 10.—STEPPE IN SOUTH RUSSIA.

causes which are still operating on its surface. It is more to the purpose to notice, as Humboldt pointed out, that there exists a singular parallelism between the two sides of the Atlantic, north of 10° South latitude, "the projecting angle of the one corresponding to the receding angle of the other." Thus the Gulf of Guinea on the African shore corresponds to Cape San Roque in America, while the Gulf of Mexico is the concavity, which is matched by the convexity of that great headland of Africa, of which Cape Verd is the extreme point. That these peculiarities are not the result of "accident" we may easily premise. There are no accidents in Nature. But what is the cause, or what the succession of causes, which have led to this conformation, is for the present beyond our power to fathom; and it would only be idle speculation for us to discuss the many hypotheses which have been adduced in trying to arrive at some conclusion. It is, however, not too much to say that though Forster was beside the point in attributing the shape of the continents to vast floods, he had a glimmering of the truth. When we know how ceaselessly the sea is wearing away the land, it is impossible not to attribute—in part, at least—the roughly triangular shape of so many lands, namely, Greenland, Lower California, Florida, Scandinavia, Italy, Greece, India, Indo-China, the Malay Peninsula, Corea, and Kamtschatka, not to speak of Africa and America, to the ocean which laves either side. But, as we shall before long learn, the great continents are, in their broad outlines at least, of much older date than has been sometimes taken for granted; and the geologists who, when a difficulty occurred, raised up and decreed the disappearance of land-ridges, where none now exist, were reckoning without the Deep-sea Sounder, who has of late years been playing so important a part in physical geography.

Sir William Dawson has so admirably summed up the broad features of the two great oceans, that in closing our discussion of the subject we may quote his words verbatim. "If we imagine," the eminent geologist writes, "an observer contemplating the Earth from a convenient distance in space, and scrutinising its features as it rolls before him, we may suppose him to be struck with the fact that eleven-sixteenths of its surface are covered with water, and that the land is so unequally distributed that from one point of view he would see a hemisphere almost exclusively oceanic, while nearly the whole of the dry land is gathered in the opposite hemisphere. He might observe that the great oceanic area of the Pacific and Antarctic Oceans is dotted with islands—like a shallow pool with stones rising above its surface—as if its general depth were small in comparison with its area. He might also notice that a mass or belt of land surrounds each Pole, and that the northern ring sends off to the southward three vast tongues of land and of mountain-chains, terminating respectively in South America, South Africa, and Australia, towards which feebler and insular processes are given off by the Antarctic Continental mass. This, as some geographers have observed, gives a rudely three-ribbed aspect to the Earth, though two of the three ribs are crowded together and form the Europ-asian mass, or double continent, while the third is isolated in the single continent of America. He might also observe that the northern girdle is cut across, so that the Atlantic opens by a wide space into the Arctic Sea, while the Pacific is contracted towards the north, but confluent with the Antarctic Ocean. The Atlantic is also relatively deeper and less cumbered with islands than the Pacific, which has the higher ridges near its shores, constituting what some visitors to the Pacific coast of America have not inaptly called the 'back of the world,' while the wider slopes face the narrower ocean, into which for this reason the greater part of the drainage of the land is poured. The Pacific and Atlantic—though both depressions or flattenings of the earth—are, as we shall find, different in age, character, and conditions; and the Atlantic, though the smaller, is the older, and, from the geological point of view, in some respects the more important of the two."*

* "Presidential Address to the British Association," 1886.

The Islands.—Various classifications of these detached masses of land have been made.* But the one most generally adopted is that which divides them into (1), Continental (Fig. 9), and (2), Oceanic Islands, as this expresses not only their origin, and to a certain degree their structure, but is also in accordance with what is known regarding their plant and animal life, which differs in the two groups. The first class generally lie not far from some continental mass, and do not differ from the larger sea-girt continents, except by their smaller size. They are identical with the former in geological structure, and are inhabited by much the same plants and animals. Thus Great Britain is only a dissevered portion of the neighbouring continent, and a very slight elevation in the sea bed of the ocean which separates it from the rest of Europe, would speedily unite it to the mass from which it was severed at a comparatively recent period in the history of the globe. The largest continental islands are:—

New Guinea	with	306,000	square	miles.
Borneo	„	286,000	„	„
Madagascar	„	230,000	„	„
Sumatra	„	130,000	„	„

Many of these continental islands appear to be of comparatively modern date—that is, they became dissevered from the nearest continent within a period which geologists regard as recent.

Some have been divided from their border continents by comparatively newly-formed sea channels, like that which separates the British Islands from the Continent, and the Danish group from Germany. In like manner, the separation of Novai Semlai and Spitzbergen in the one case from Russia, and in the other either from Greenland or from the present portion of Europe—the former, more probably—cannot be doubted; while the Mediterranean Islands are geologically—and often as regards their mountain ranges also—simply dissevered parts of the continent to which they geographically belong. This disseverance of others from the continental mass of which they formed a part, very probably dates from a much more ancient period. Ceylon, Madagascar, and Tasmania are examples, while New Caledonia and New Zealand appear to be remnants of what were formerly large independent continental masses. There are, of course, also volcanic islands near continents, which are of very recent date.

The Oceanic Islands are, however, of an entirely different order. They are scattered on the bosom of the ocean, and are surrounded by very deep water, which debars the idea of supposing that any broken-down land communication ever existed there, even did not the positive testimony of the sounding-lead leave no doubt on the subject. Some are of volcanic origin—islets vomited out of the abyss, or, more strictly speaking, the tops of submarine volcanoes, such as are still at intervals displaying their activity in the Pacific and other oceans; others are composed of coral, resting on the flanks of volcanoes and mountain-chains, and built up by the coral polyp eliminating from the sea the lime to form its tube. It does not, of course, necessarily follow that all volcanic islands are oceanic. Only, all oceanic islands are either volcanic or coral, or both combined. Were they anything else they would be fragments of some large submerged continent, which in no case are they. The volcanic isles off continents always lie in the region of active volcanoes, and sometimes, like the Kuriles and Aleutians, take the form of chains; or, like the Sandwich, Fiji, Tahiti, and others, form groups; or, like Iceland, Jan Mayen, Ascension, St. Helena, Tristan da Cunha, St. Paul, Amsterdam, &c., are isolated. The Coral Islands—the low-lying islands of the South Sea—strictly speaking, are oceanic islands, which never rise higher than from one or two, or at the utmost, three or four yards above the surface of the sea. These coral islands may also be regarded as due to accumulation; for, as the polyp cannot come to the surface, they must be raised above the surface either by volcanic action or by the waves tossing up blocks of dead coral. Then, the birds bring

* Hahn: "Insel Studien" (1883); Wallace: "Island Life" (1880).

seeds, and the plants which spring from the seeds that they bring form a soil on which grows the vegetation they are covered with. As no quadrupeds could reach them from the continents, the oceanic islands contain no truly native mammals or amphibians —the life usually consisting of such reptiles, birds, or insects, as could have reached them

Fig. 11.—ISMAÏL'S VALLEY NEAR THE DACHEL OASIS IN THE LIBYAN DESERT, NORTH AFRICA.
(*After a Photograph.*)

either by flight or by the influence of the winds and currents wafting to their shores trees and other driftwood. When the insulation of a continental island has been of long duration, it not unfrequently happens that it also contains a few plants and animals different from those of the mainland, or peculiar to itself, the modification being due to the isolation to which such forms have been exposed. This, however, is a subject which will be more fully discussed when the laws regulating the distribution of life come to be explained.

The Littoral or Coast islands may be regarded as forming a final group of islands which cannot quite come under either of the foregoing heads. Coast islands, for the most part of an insignificant size, are often seen in swarms along the shores of continents or large islands. They were formed either by drift or by accumulation,* like the alluvial islands (sand and mud banks) at the mouth of large rivers, carrying much mud in suspension; examples are supplied by the isles of Usedom and Wollin at the mouth of the Oder, the islands at the mouth of the large Siberian rivers, and the isles of the Mississippi delta. Or they may be heaped up by wind and sea-breakers, like the sand islands of the Atlantic and the Gold Coast. Another group of islands is due to mechanical erosion.† Their communication has been divided by the washing off and the tearing away of the projecting

* They are the "Aufschüttungsinseln"—accumulation islands—of Kirchhoff and Hahn.

† "Erosionsinseln"—erosion islands—of Hahn.

TE TARATA, NEAR ROTOMAHANA, NEW ZEALAND

'BOILING CAULDRON WITH THE TERRACES OF SILICIOUS DEPOSITS

(AFTER HOCHSTETTER).

continental parts. To these belong the "Skjären" (or skerries), the rocky islands on the coast of Scandinavia and Scotland, and the numerous islands with which all fjord-cut coasts are littered. Fjords we shall consider later on.

The Mean Height of Continents is, according to Laplace, about 3,280 feet, though Humboldt estimated the elevation of Europe at only 1,010 feet. As central Africa had not been explored when the great German geographer made his calculations,* he could only guess at the elevation of the interior of that "dark continent." However, with our present knowledge, it may be accepted that the mean height of Asia is equal to that of Africa, and that of Australia almost equals that of Europe. If so, the mean or average elevation of all the continents would be 1,135 feet, Asia and South America being the highest, Europe and North America—leaving Africa out of the reckoning—the lowest. Of late Gustav Leipoldt † has re-calculated the data on which Humboldt based his generalisations, so far as Europe is concerned, with the following results:—‡

States.	Mean height in feet.	Area in square miles.
Russia	550	1,743,200
The Spanish Peninsula ...	2,296	175,904
Scandinavia	1,404	221,200
Austria	1,698	180,928
Balkan Peninsula	1,900	131,232
France	1,290	156,392
The Italian Peninsula... ...	1,664	86,112
Germany	667	158,912
Great Britain	712	92,288
Switzerland	4,263	11,840
Denmark (including Iceland)	1,155 §	41,392
Roumania	922	35,152
Belgium	535	8,560
Holland	159 ‖	10,288
		3,053,400

* Humboldt: "Kleine Schriften" (1853).

† "Über die mittlere Höhe Europa's" (1874).

‡ The decimals are omitted, as the calculations are, at best, only approximate.

§ Denmark itself is very low. Bavnehöi, near Skanderborg (550 feet high), is the loftiest summit in the kingdom.

‖ A large extent of Holland lies actually under the level of the sea.

Accordingly, accepting the opinion of Krümmel that the other parts of the globe were, unlike Europe, considerably underrated by Humboldt, we may take the following figures, in round numbers, as the average heights of the continents:—

Europe	984 feet.
Asia	1,640 „
¶ Africa	1,640 „
America...	1,345 „
Australia	820 „

The mean height of the continents would therefore be 1,285 feet. The latest calculations put the mean depth of the oceans and seas at 2,000 fathoms,** which is diminished to 1,880 fathoms, in consequence of the shoalness of the littoral zone and of the narrow seas. Thus the mean height of the continents appears to be not more than one-eighth as much as the mean depth of the seas by which they are surrounded.

The volume or bulk of the continents, so far as they lie above the level of the sea, is calculated to be 146,750 cubic miles, which will give 3,144,380 cubic miles for the seas of the world. Comparing these two figures, they are as 1 to 21·4. The seas therefore comprise 21·4 times the continental masses, and, if all the inequalities of the continents cast off into the seas be taken into account, the slight loss of the mean depth would amount to no more than 87 fathoms. The North Atlantic basin, the area of which is 10,124,800 square miles, or nearly as large as the surface of all the continents, could alone almost embrace more than double (2·26) all the continents lying above the level of the sea; or, if the whole of these were tossed into the basin of the ocean, they would diminish its depth to only 1,163 fathoms. If, remarks Peschel,†† the portions of the continents projecting under the level of the seas were removed so as to present a plain, by making

¶ Chavanne in 1881 estimated the mean height of Africa at 2,168 feet, which is unquestionably too high.

** A fathom, in which depths are usually computed, is six English feet.

†† "Physische Erdkunde" (1879), p. 424.

the bed of the Atlantic of one uniform level, the hollow space remaining would be sufficient for an ocean extending above the level of the Atlantic, while the engulfed continents would be still left with a depth around them of 240 fathoms, or five times deeper, on an average, than the North Sea. From these calculations we perceive that the inequalities of the continental masses are very slight when compared with the bulk of the continents, which rise like immense plateaux from the top of the ocean. Viewed from the bottom of the North Atlantic, the shores of the earth would appear like elevated plains 11,300 feet high, or higher than the crest of the Alps, above the level of the sea.

The Bottom of the Sea.—Of the shape of the bottom of the sea we can form only an approximate or general idea. The places covered by the ocean are protected from the destructive agencies which are the principal means by which the rest of the earth has been given its present relief. The force of the currents is least at great depths. The wind does not act, and of course the rivers, and the glacier, and the rainfall, are equally inoperative at the bottom of the sea. The bed is, however, sinking in certain places and rising in others, so that, to a certain moderate degree, we can premise what like the covered portion may be or what like it actually is. But for the great depths only the sounding-lead is available as an interrogator. This cord tells the number of fathoms through which it sinks before land is reached, and the material brought up on the tallow of the "lead," or in the more effective apparatus which, for scientific purposes, has displaced that primitive instrument, affords a tangible indication of the geological constituents of the bottom. From researches conducted in this fashion, we are able to say that, in general terms, there are elevated plains, hills, and valleys, deep glens, and sharp ridges beneath the ocean, just as there are above it, though the differences of levels are, for the most part, united by gentle slopes. The sea bottom is, however, not a repetition of the dry land, so far as its configuration is concerned. Near the coast the land under the ocean is generally, for some distance at least, similar to that which borders it. If, as on the west coast of England, the shore is high, or, as on the east, a plain, then it will be continued with the same character for some distance out to sea. But once the depths of mid-ocean are reached, the variation is less—so little, indeed, that were the observer to be placed at the bottom of the sea the country around him, with its gentle undulations, without abrupt changes, would appear almost like a level plain.

The volcanic and coral islands are exceptions to this rule, as they rise, in many instances, almost abruptly from the depth of the sea; while the continents rise gradually and gracefully from the depths of the ocean to immense high plains, the inequalities of which on the surface are, as we have seen by comparing the masses together, very small in comparison with the immense foundations upon which they are built up from the depths of the sea.

The present coast lines nowhere define the true border line of continental elevation and oceanic depression. Along the continent is often found a more or less wide zone of an inferior depth of the sea, in which the continents under the sea form an ocean basin. This submarine border of the continents is generally defined by the 100-fathom line, from which line the sea depths advance rapidly, so that, in some instances, the 1,000-fathom line lies nearer to the coast than the 100-fathom one. Thus, for example, the only boundary-line between Europe and the Atlantic basin is the 100-fathom line, which extends from the South of Norway, round Scotland and Ireland in a southerly direction to the Bay of Biscay. In this manner Great Britain appears as a part of the European continent. This submarine continent stretches along the coast of North America far into the sea, and forms the well-known banks of Newfoundland. The most remarkable example of this is the south-east of Asia, where there is a shallow arm of the sea between the Malay Peninsula and Sumatra. Between Java and Borneo the depth is not

more than 50 fathoms, but between Borneo and Celebes, in a north-southern direction, a depth of 100 fathoms is recorded. The same depth prevails between New Guinea, Australia, and Tasmania, and between the Japanese islands and China similar conditions obtain; while it forms a band connecting America with Asia across Behring Strait, Ceylon with Hindostan, and the Falkland Islands with the South American continent. The 500-fathom line connects North America, Greenland, Iceland, and the Færoe Islands and the continent of Europe. The 1,000-fathom line connects New Zealand with Australia, Madagascar with Africa, and nearly exhausts the depth of the more or less land-locked seas which lie between Australia and Asia, Africa and Europe, North and South America, and of the seas situated between the Arctic and Antarctic Circles. The Cape de Verde Islands and the Canaries belong to Africa, Madeira to Europe, and less than 500 fathoms divide Norway from Spitzbergen.* The great depths, we shall by-and-by see, are, in most cases, of very ancient date, and point to a long disseverance between the masses of land which they divide, with corresponding differences in the plants and animals of the two localities, places comparatively close together —as Bali and Lombok, in the Malay Archipelago—but separated by a deep strait, being, so far as their fauna are concerned, different regions; while other islands much farther apart, though with a shallower sea intervening, are to a great extent identical in these respects.

Another fact which recent deep-sea dredging expeditions have brought to light is that the great depressions in the bottom of the ocean are of very ancient date. We see rivers bringing down silt and depositing it in the sea, and the waves tearing down the cliffs, and then throwing the *débris* into the water beyond. The coarser fragments naturally sink first—that is, nearest to the land; the lighter are carried farther out, while the fine mud is drifted to a still greater depth. But nowhere does the sounding-lead, in the abyss of the ocean, bring up any land-derived materials. The transporting power of the currents gradually lessens, and finally altogether ceases, so that the land-derived materials are not found at a greater distance from the shore than from 60 to 300 miles, or at a greater depth than about 2,000 feet, being thus confined to a comparatively narrow belt round the margins of continents and islands. In the vast area over which no such land-borne materials are deposited, a remarkable red clay and various kinds of ooze, made up largely of the shells of the jelly-specks called foraminifera, mollusca which live in the open ocean, and of similar organised beings, are found (Fig. 12). The red clay is very widely distributed. Indeed, it has been found wherever the "abysmal regions of the oceanic basin" have been sounded. It is described as extremely fine-grained, and owes its deep brown or red colour to the presence of the oxide of manganese and iron. "Scattered through this deposit occur particles of various minerals of volcanic origin, together with lapilli and fragments of pumice, *i.e.*, volcanic ejectamenta. Such materials may have been thrown out from terrestrial volcanoes, and carried by the winds or floated by currents until they became water-logged and sank; or they may to some extent be the relics of submarine eruptions. Whatever may have been their immediate source, they are unquestionably of volcanic origin, and are not associated with any truly terragenous sediment. The red clay is evidently the result of the chemical action of sea water on volcanic products, and many facts conspire to show that its formation is an extremely slow process." Thus, remains of back-boned animals, consisting of the ear-bones of whales, the teeth of sharks, and so forth, are often plentifully present, though there is no reason to suppose, as Murray and Renard point out, that the parts of the ocean where these remains occur are more frequented by sharks and whales than the regions where they are rarely or never dredged up. These remains seem to have lain there for a long period, for they are thickly coated with manganese and iron, and belong to extinct species. Meteoric dust, ejected from celestial bodies immeasurably distant from the earth, is also mixed up with this covering of

* Wild: "Thalassa" (1877), p. 13.

the ocean bed. All the facts of which we are at present in possession go to dissipate the idea, until very lately almost universally held, that every inch of ground now above the sea might in some remote period have been covered by thousands of fathoms of water. When we find marine animals embedded in rocks at the summits of mountains, there is no escaping the conclusion that the sea once rolled over the materials out of which these rocks are composed. But it does not necessarily follow, they are coral structures founded upon the shoulders of degraded volcanoes and mountain-chains, and built up to the surface by the indefatigable labours of the humble polyp. We come, then, to the general conclusion that oceanic basins and intervening continental ridges are great primeval wrinkles in the earth's crust—that they are due to the sinking down of that crust upon the cooling and contracting nucleus. These vast wrinkles had come into existence long before the formation

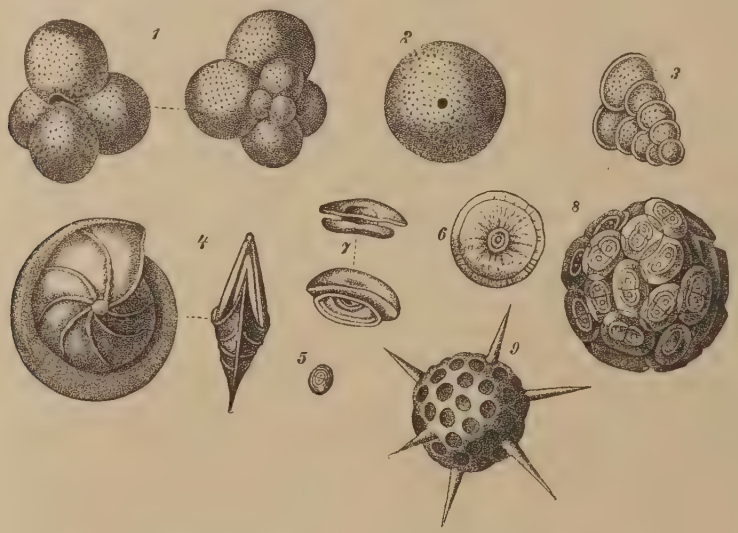


Fig. 12.—SOME CONTENTS OF THE DEEP SEA SLIME (*Globigerina ooze*).

1, Globigerina bulloides; 2, Orbulina universa; 3, Textularia; 4, Cristellaria; 5, Coccolith; 6, 7, Discolith; 8, Coccosphere; 9, Haliomma (Radiolarian). [All highly magnified].

after what is known of the constant action of the elevating and depressing agencies on the earth's crust, that when the rocks on the tops of the mountains were formed, they were as far below the surface of the sea as they are now above it. On the contrary, it is now generally held that "abysmal waters have never prevailed over the regions now occupied by dry land; nor is there any evidence to show that continental land masses ever existed in what are now the deepest portions of the ocean. The islets dotted over the surface of the Pacific and the other great seas are not the relics of a vast submerged continent. They are either the tops of submarine volcanic mountains or of our oldest geological strata. All our rocks may, in short, be looked upon as forming a mere superficial skin, covering and concealing the crystalline materials which no doubt formed the original surface of the earth's crust." *

Vertical Elevation of the Land Masses.

Lowlands and Highlands are the two great divisions into which the dry land may be divided, if we consider it as regards its elevation above the sea. There are plains and

* James Geikie: "The Geographical Evolution of Europe" (*Scottish Geographical Magazine*, Vol. II., pp. 193—207).

swampy lands in contradistinction to mountains or hilly country. The plains or lowlands are commonly found in localities which bear evidence of having been at one time under the sea. They are usually under a thousand or eleven hundred feet in height, and, as might be expected, generally skirt the sea-board of continents, stretching into the interior in the form of broad valleys. One plain—the largest in the world—stretches from the centre of our Islands across Europe and Asia, ending in the north by the shores of the Arctic Ocean, and in the south in Asia Minor and Eastern Siberia, though, of course, divided into two by the Oural Mountains. Another great plain is that which is spread along the eastern sea-board of America, extending up the broad valley of the Mississippi. Many of these plains, it is clear from the evidence of the marine remains found in the soil, formed, in periods geologically very recent, the bed of the sea, and, were the level of the land to be slightly depressed, would again become, in part at least, an expanse of water. Some plains—the Pampas and the Tûndras, for example—are formed by the beds of rock beneath retaining their original horizontal position; while the limestone plains of Ireland and the plains of Cheshire are, among others, due to "marine erosion" of the upturned edges of the underlying strata. Either before or after the sea covered these plains, the rocks got broken, twisted, bent, and disturbed in all manner of ways by the subterranean movements always going on. But the level not having been altered, the sea soon wore them down, shaved them, as it were, into a uniform smoothness, just as the plane of the carpenter reduces the irregularities of the plank to one level.

Fig. 13.—"PUSZTA" OR PLAIN OF HUNGARY.

Their borders are generally marked by terraces which tell plainly the tale of gradual elevation. Any point above 1,100 or 1,200 feet is usually regarded as high land; any less mean elevation may be taken as low land. A certain physiognomical character is common to all the extensive plains, which occur in the large continents, in the possession of a very uniform vegetation, or in being very bare of plant-life. In North-western and Central Europe they are known as "Heaths;" in Hungary as "Puszten" (Fig. 13); in South Russia and Western Asia as "Steppes" (Fig. 10); on the northern coast of Russia and Siberia as "Tûndras;" in Africa as "Deserts" (Fig. 11);

in North America as "Prairies;" and in Spanish America as "Savannahs," "Pampas," or "Llanos." Most of these are of a very recent geological date, which may be indicated by the limits of the Tertiary seas. We see in this manner basins formed in similar localities, such as the basin of Vienna, the great Hungarian basin, the London and Paris basins, &c. But where a rapidly-flowing river descends from heights we see that the basin is coterminous with the bed of the river, as the watershed of the Po, the river-bed of the Rhine, the Delta of the Ganges, and the lowlands of the Mississippi. All these newer formations are composed by detritus from the highlands, composed of sand, boulders, clay, and loam. In them are frequently found the saline efflorescence which may be seen in the Hungarian plains and in the Russian steppes, and above them we may see the deposits of turf, which are noticeable in the German Sarmatian plains.

Some of these depressions in the inner portions of continents might be converted into inland seas if there were a general depression of the crust of the earth. Under such a condition the waters would easily flow into them. From the Black Sea to the Caspian we observe such a depression, the effect of which has been to throw the level of the Caspian more than 82 feet below the surface of the ocean, its bed being on an average 2,982 feet lower still. A similar depression or dislocation causes the Jordan to run in a glen, the termination of which at the Dead Sea is 1,298 feet below the level of the Mediterranean; while the bed of the Dead Sea is in places 2,598 feet below the surface of the nearest sea.* The highlands are composed of upland forests, hills, and mountains; and between the levels of the plains and the highlands we often see "foot hills" arranged in a terrace-like form.

Table-lands.—Plateaux, or upland flats, are never found at a lower elevation than 1,300 feet. These table-lands occur in various parts of the world, and though in many cases bare and waterless, from their healthy position they have become the centres of a considerable civilisation, especially when, as in America, the lower regions are tropical. Munich is on such a plateau, 1,673 feet high; and Lhasa, the isolated capital of Tibet, is built in the midst of those vast levels on the other side of the Himalayas, which attain an elevation, as in the Kuenluen, of from 10,000 to nearly 13,000 feet. Quito, the capital of the South American Republic of Ecuador, is placed at an elevation on the Andes of 9,528 feet; while the wonderful civilisation of the Aztecs and Toltecs of Mexico, and of the Incas of Peru, was alike matured at great elevations, the people of the dense tropical forests at lower heights never rising above the savagery of the American tribesmen. The city of Mexico stands 7,482 feet, and Cuzco, the capital of the Incas, 11,380 feet, above the sea; while Santa Fé de Bogota, in Colombia, is at an elevation of 8,413 feet. Table-lands lie sometimes on the surface of beds of rock which, though apparently horizontal, are in reality "in curves, the bends occupying long distances, so as to be almost imperceptible in some cases," but visible, even to the untrained eye, in others. Dr. Duncan cites High Peak or Kinder Scout, in Derbyshire, as a small, though fine, example of this kind of table-land. The flat-topped hills of the Black Mountains, which the spectator can see in the distance as he stands on the top of the Malvern Hills, looking to the west towards Wales, may also be regarded as good types of English plateaux. On the summit of the Cotswold Hills is a greater table-land, with a slight slope to the east, though, of course, small compared with those mentioned, or even with the table-land of Magdala, the basaltic plateaux of the Coiron, in central France, or the numerous plateaux which are found in the Atlas and other mountains.

These plateaux owe their character mainly to the absence of water. Were they subject to great rainfall, or to the action of rivers, they would soon cease to be table-lands, and would be cut up into mountains, divided from each other by valleys, at the bottom of which

* Hull: "Mount Seir" (1886); "Physical Geology and Geography of Arabia Petræa, Palestine, &c." (1886).

a stream flowed, or, if the strata were more resisting, by gorges through which roaring currents found their way to the sea. These plateaux are found more or less everywhere, and are either on the summits of mountains or arranged on terraces around them, and in every case are coterminous either with an axis of depression or elevation. Their influence on the climate is remarkable, and, indeed, to the circumstances about to be described they owe much of their present condition. They are deprived of the revivifying influence of the rain-clouds which, in drifting inland, are arrested by the mountains by which the table-lands are surrounded, the contents of the clouds being precipitated on the side of these greater elevations. This we see in Asia. The tropical winds, arrested by the Himalayas, discharge an abundant rainfall on the southern slope of that range, so that up to the line of perpetual snow there is luxuriant vegetation. But when we come to the plains of Tibet, on the other side, we find aridity in place of moisture, and a scanty amount of grass in place of tropical and semi-tropical verdure. The surfaces of these table-lands—as Ritter, Humboldt, and Guyot have pointed out—more heated than the layers of air of the same level, suck up like a sponge the little vapour it contains, without condensing it, while their extent and elevation tend to impede the access of the oceanic vapours and to increase the drought. This we see well marked in the plateaux of Central Spain, though these table-lands, on one of which Madrid is built, are only from two thousand to twenty-five hundred feet above the level of the sea; for while the south-west coast of Portugal—Lisbon, for example—is watered with twenty-seven inches of rain, the border of the table-land has only eleven inches, and at Madrid, near to the centre, not more than ten inches of rain water fall in the course of twelve months. This is the lowest amount deposited on any place in Europe. Yet at the western foot of the Sierra d'Estrella, in the valley of Mondego, Coimbra is reported to have received in one year the enormous downpour of 225 inches. But even allowing that this record, which was for 1816–17, is affected by some error, and that 118 is nearer the truth, we have at two localities, in very nearly the same latitude, and in the same peninsula, a difference of more than 100 inches in the amount of annual rainfall—all owing to the difference of geographical position between Madrid and Coimbra, the plateau of Castile being 2,238 feet above the sea, while the lower lying Portuguese university town is exposed to the whole force of the moist Atlantic winds.

What we see in the small plateaux of Spain is noticed much more markedly in the great table-lands of Eastern and Western Asia, which, owing to their vast extent, their height above the sea, and the fringe of snowy mountains which shut them off from the beneficial influence of the sea-breezes, are almost or wholly deserts. In like manner, the plateaux of Southern Africa — the "veldts" of the Transvaal, for example (between six and seven thousand feet high)—are singularly dry, while those of Mexico and Nevada are, compared with the immediately adjoining region at a lower elevation, and in a different physical situation, parched during a great portion of the year. At Vera Cruz, for example, the average rainfall is 62 inches, while at the city of Mexico there is a very moderate amount, though, curiously enough, the heaviest recorded rainfall (90 to 100 inches) occurs in the Huatusco district, at an altitude of 4,380 feet, owing to the fact that the uplands facing seaward are often wrapped in the fogs and mists of the Atlantic winds, and, as in the present instance, are deluged beneath the precipitated contents. It has often been supposed that the prairies of North America, and the corresponding treeless tracts in the southern part of the continent, with the steppes of the Old World, are treeless, owing to the lack of water during the growing season. Of late, however, this idea has been generally abandoned, owing to the exact observations taken showing that, though the moisture received by such situations is little, it is not insufficient for the growth of trees on the prairies, whatever may be the case in the table-lands, which do not come within that

designation. Professor Whitney advocates the theory that the extremely comminuted character of the soil has more to do with this than anything else. "Where, for any reason," he contends, "the soil is of especially fine texture, there grasses will flourish in preference to forests, provided the rainfall is not entirely insufficient. Hence we see at once why plains Mauvaises Terres, or "Bad Lands" of Western America (Fig. 14), owe their peculiar character to the soft permeable rocks of which they are composed, wearing away into forms of the most striking and even picturesque character, though utter sterility, due partly to the nature of the rock formation, and partly to the extreme dryness of the climate, holds

Fig. 14.—"BAD LANDS" NEAR FORT BRIDGER, WYOMING TERRITORY, U.S.A. (*After a Photograph.*)

are more likely than mountain slopes to be treeless. It is towards the plains that the finer materials, abraded by erosion and denuding agencies from the higher regions, are being constantly carried, as they have been in former geological ages. The broader the plain the more likely it is that a considerable portion of it will be covered with fine detritus, whether they be of subaërial origin or deposited at the bottom of the sea."* The true of all of them. These broad and nearly level tracts, known as "Parks" or "Holes," within the area occupied by the ranges properly designated "the Rocky Mountains,"

* "The Earth's Treeless Regions," in *Science for All*, Vol. V., pp. 124-133; see also Duncan's description of Table-lands, in Vol. III., p. 352. Professor Newberry, however, altogether denies the soundness of Professor Whitney's views, contending that the treeless character of great tracts of the American continent is entirely due to absence of moisture.—"Notes on the Geology and Botany of the country bordering the North Pacific Railroad" (*Annals of the N. Y. Academy of Science*, Vol. III., 1884, pp. 242—270); and "Countries of the World," Vol. I., p. 195; Vol. II., pp. 74—88; Vol. III., pp. 83, 103; and Vol. VI., p. 206.

Fig. 15.—THE ROCK OF GIBRALTAR (DOLOMITIC LIMESTONE), FROM THE "NORTH FRONT."

(*After a Photograph.*)

were the beds of lakes, which had become dry during later Tertiary periods, and, like the prairies proper, they are almost entirely destitute of trees.

It thus appears that these plateaux are to a great extent due to the action of water in former times, while their characters in more modern days must be traced to the causes at present in operation, though it may be regarded as an open question how far the fine character of the soil favours grass in preference to trees. High winds sweep over them, and where the soil is not thickly covered with turf, the dust, which the dryness, combined with the absence of stones, favours, is often carried so far that the snows in the south and south-east of Russia are sometimes rendered dirty by the dust raised by wind on the Caspian steppes, and a similar account applies to the dust whirlwinds of the Orinoco and other treeless regions of the world.*

The dryness of the interior basins of great continents also gives rise to the saline efflorescences which so frequently gather on their surface. This we see in the steppes of Southern Russia, in the "llano estacado" of New Mexico (3,200 to 4,700 feet above the sea), in the "alkali" wastes around the Great Salt Lake of Utah, and in the sage brush region of Nevada, so familiar to every traveller in that country. These encrustations are the salts dissolved out of the soil by the rain which has sunk into it, and which, rising by means of capillary attraction, evaporates, and leaves behind the extraneous matter with which it was laden. Alkali soil and alkali water are dreaded of the Western traveller. The Klamath Lakes in Oregon are, for example, utterly undrinkable from the amount of the efflorescences which have been drained into them by their feeding streams. It may be added, before leaving this subject, that some table-lands, like that of Spain, are sharply divided from the surrounding country by a somewhat abrupt boundary. In other cases they gradually slope upwards from the adjoining plains, as in the country west of the Missouri; or, as in the case of Quito, the plateau may be surrounded by mountains, while, as so aptly described by Archibald Geikie, the Rocky Mountains "stand" on a plateau platform. If, however, a table-land is to preserve its character, an absence of water, or at all events of running water, is absolutely essential. Thus, we see the "fjelds" of Norway being gradually converted from level or undulating plateaux into a broken upland furrowed by rivers, and in time destined to be a clump of mountains divided by valleys, through which flow the streams which have eaten them out of the original table-land.

Isolated Rocks.—Sometimes in the highlands, as well as in the table-lands, and sometimes on the low-lying plains, we come upon lofty isolated rocks, dissevered from any similar surroundings. They appear like islands in a sea of land. To the geologist these rocks are of peculiar interest, for they open up to him a vast field of inquiry. Sometimes they are due to volcanic action. The subterranean forces have vomited forth lava, which, as in the case of many islands, like Ascension, leave a lump of slag or a mountain of cinders in mid-ocean. In other cases they are the remnants of very ancient volcanic action. In some remote period of the world's history there had been vast outbursts of this kind of fury, which forced immense discharges of lava through the overlying beds of softer rock. In time, by the constantly wearing away of the surrounding rocks, this hard "trap" or "whinstone," as we call it, is left isolated, being the last to resist the action of the rivers, the rains, and the other disintegrating agencies. This is well exemplified in the Dumbarton Rock, Ailsa Craig, the Bass Rock, and a host of similar well-known landmarks in the scenery of this and other countries. In other cases, as in the Rock of Gibraltar (Fig. 15), the eminence appears as if broken off from the central axis of the range to which it naturally belongs. In these instances denudation—the wearing-way process which we have indicated—has been going on around the island rock until it has become isolated from its system, the Hohenstaufen, Hohenzollern, and other high

* Humboldt: "On Steppes and Desert," in "Views of Nature," Vol. I., pp. 1 225 (Mrs. Sabine's Trans.).

mountains of the Swabian Alps, being also examples in point.

One of the most interesting of these isolated rocks, or rather mountains, is Roraima, in British Guiana. It is between 8,000 and 9,000 feet in height, or about 5,000 above the level of the plain from which it rises isolated, with almost inaccessible precipices on every side. Roraima is, in short, as Mr. im Thurn, who first ascended it, writes, a flat-topped pillar, itself some 2,500 feet in height, set on a very steeply-sloped truncated cone of about another 2,500 feet in height; or, rather, "first imagine a flat-topped mason-wrought pillar of about 25 feet in height, set on a steeply-sloped pediment of another 25 feet," and the difficulty of reaching the summit of Roraima may be imagined. Yet the mountain is not solitary, unique, or peculiar; for though remarkable in form, it is only the most famous, slightly the most lofty, and perhaps really the most striking of a group of similar mountains. Their shape is due to the wearing-away of the rocks around their base. Just as in winter when a thaw has set in after a heavy snow, on the vanishing snow-drifts small pillarets of snow, capped and protected each by some small pebble, are ranged over the surface; so in the tropics, after some terrific downpour of rain, similar pillarets of earth remain on some thrown-up heap of loose soil. On the savannah, where the surface conglomerate protects the soil beneath, these "eppelings"—as the Indians call them—are very frequent. "Eppelings" on this comparatively small scale abound in the vicinity of Roraima, which Mr. im Thurn regards simply as an "eppeling" on a gigantic scale, formed in the same way, and like its companion pillar-mountains altogether, except in its gigantic size, equivalent to the pillarets on the loose water-washed earth, to the pillarets of snow on the snow-drifts, or the ice pillars which in exactly similar circumstances are so frequently seen on glaciers. The summit is not quite flat, and is dotted with numbers of grotesque pillars—"eppelings" again—which are gradually melting away, like the snow mass in a thaw, under the influences of the rain, and wind, and mist, which in a region "the very home of all mists, and rain, and storm, and winds," exercise in an almost unapproached degree their powerful sway. Here gather the streams which flow in various directions to swell the torrents of the Orinoco, the Essequibo, and the Amazon. Roraima, as the Indians say, is the "mother of streams." Its summit is, in reality, a very slightly hollowed basin, in which the moisture condensed by the countless pillars of absorbent sandstone which cover its surface collects. These tiny streamlets are rapidly cutting for themselves deep channels through the rim of the rock-basin before emerging from it in one wild leap over the steep precipice.* Mount Twekkway, about fifty miles NNW. of Roraima, is a similar elevation, though not so high. It is flat-topped, with vertical walls, but differs—according to Mr. Whitley, who ascended it in 1886—in being wooded at the summit, and in the water not falling over the edge of the plateau, as in Roraima, but draining off by a cavity of great depth in the middle. The Sierras de Ereré and Obidos, the table-topped mountains so noticeable in ascending the Amazon River, and the somewhat similar formation on the opposite bank at the rear of Santarem, are also quite conformable with Roraima. Such hills are found in many parts of Brazil, and are really gigantic pillars cut by the action of water and rain from the body of the great plateau of which they originally formed a part.†

The *buttes* of Western America—detached hills, mountains, or knolls from which the surrounding beds have vanished—are also remarkable examples of the isolated rocks which form the subject of this section; though, just as the term "cañon" has been misappropriated to describe any deep river defile, the word "butte" has of late years been applied to mountains which in no way correspond—Shasta Butte, for example—to those which suggested the name to the early

* Im Thurn: *Scottish Geographical Magazine*, Vol. I., pp. 548–553.

† Wells: *Proceedings of the Royal Geographical Society*, 1886, p. 359.

voyageurs of the fur-traders. The French term *massif*, which is given to blocks of mountain ground, such as the Matterhorn, the Jungfrau, and the Glärnisch in the Alps, is also entirely inapplicable to the kind of geographical features which we are describing. These blocks come under the head of mountains proper.

Mountain Shapes.—Apart, however, from the causes that have led to their formation, and which will come to be more fully discussed at a later stage, the geographer recognises, as regards their shape—cup-shaped, massive or table, and chain mountains. In these descriptions of elevated lands all kinds of rocks are found—volcanic, granitic, and porphyritic; but the first named enter for the most part into the composition of the cup-shaped or crater-topped mountains, which are generally extinct volcanoes. A familiar example is afforded by the middle range of the Leitmeritz mountains of Bohemia (Fig. 16), the Euganean hills of Padua, the extinct volcanoes of Auvergne in France, the volcanic Eifel in Germany (where many of the old craters are, as is also the case in the extinct volcanoes of the Cascades in Oregon, occupied by lakes), the Siebengebirge, &c. In these islands there are many such hills, though none perhaps as marked or of such recent date as those mentioned.

The massed mountains are so common that examples may be cited in the large mountain-chains of almost any part of the world. The successive horizontal beds which cover their flanks indicate that the strata of which they are composed were deposited in various epochs of the earth's history. Their development has been so gradual, and the periods during which they have been accumulated so vast, that all these mountain-chains have had time to be intersected by "faults" or dislocations, as well as by outbreaks from the eruptive rocks below. We see, as a result of this combination, that the axes of the mountain-chains have been shifted, and that other and ancillary chains are developed at different angles to the main one. The primitive form of the mountains has become changed in time by the action of wind and water, which has produced "weathering." Diagrams of the principal mountains are sufficient to demonstrate these facts (Figs. 16, 17).

When mountains get massed into clumps, their average elevation does not vary much. This we see in the Scandinavian peninsula, in Scotland, in the north and west of Ireland and England, in Normandy and Brittany, in the south of France, in the Hyères Islands, in Sardinia and Corsica, in most part of the Spanish peninsula, in the Vosges, the Black Forest, and the chains of Bohemia, Moravia, Silesia, &c. These ranges are of unequal shape and development, but generally take a longitudinal direction, so as to form a series of elevated masses. The loftier portions of these groups usually run towards the south-east, with the exception of the Scandinavian peninsula, where the north-west has that pre-eminence over most of the region, or from the south-west to the north-east, which is the rule in the Bohemian and Moravian mountains.

"Chained" mountains, like the Himalayas and the Andes, may be regarded as the backbones of continents. They run in direct lines, of which the length is much greater than the breadth; though, looking at the conventional signs on maps, one has some difficulty in understanding that a range like the Rocky Mountains is, in reality, a vast mountainous region instead of a single chain, and, the great heights apart, that, owing to the long distance of the mountains from the sea (from the level of which the altitudes are measured), the elevations are not higher than they seem, or more imposing than lower chains farther west.* The Cascades are much more striking; so are the Andes from the Pacific; and, though the average height of the New Zealand Alps is less than that of the North American cordillera, they present, owing to the causes mentioned, a more striking appearance.

The loftiest point at present known is Gaurisankar or Mount Everest, in the Himalayas, 29,002 feet high, though Dapsang, in

* Examples of this are given in "Countries of the World," Vol. I., p. 272.

the Karakoram of Western Tibet (28,271 feet), Kinchinjinga, on the frontier of Sikkim (28,150 feet), and Dhavalagiri (26,079 feet), run it closely. The absolute heights of the South American mountains are not much behind those of the Asiatic chains. Aconcagua, in Chili, is 23,290 feet high; Sahama, in Peru, 22,000 feet; Nevada de Sorata, in Bolivia, 21,286 feet; Illimani, 21,181 feet; and Chimborazo, in Quito, is fully 20,703 feet high;

Fig. 16.—VIEW OF THE LEITMERITZ "MITTELGEBIRGES," AS AN EXAMPLE OF CUP- OR CONE-SHAPED MOUNTAINS, FROM RZIP (GEORGSBERG).

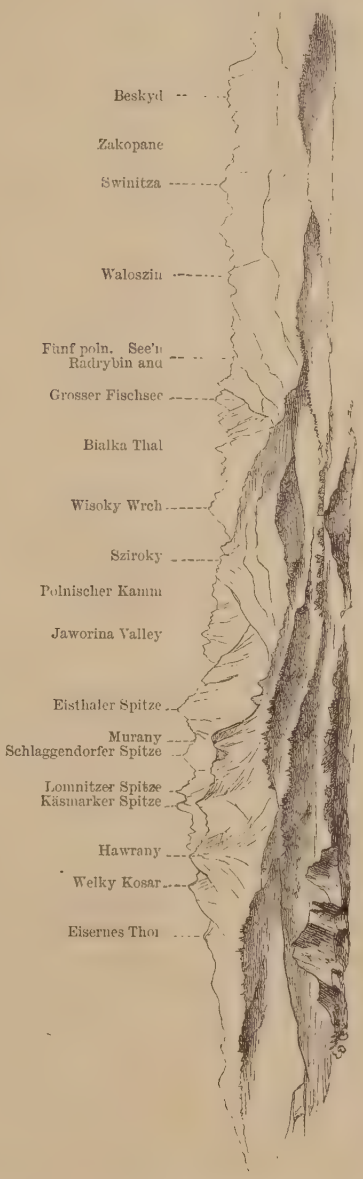


Fig. 17.—VIEW OF THE TATRA MOUNTAINS (CARPATHIANS), AS AN EXAMPLE OF A MOUNTAIN CHAIN, FROM THE BIELSKA SKALA, IN THE PLAIN OF NEUMARKT (GALICIA), WITH LITTLE CHALK HILLS IN THE FOREGROUND.

though the exact elevation of the Andean peaks has still to be ascertained by processes more scientific than those by which the heights given have been obtained.

Little over half the elevation of the loftiest Himalayan peaks is reached by the highest mountains of Europe. Mont Blanc (Fig. 19) is 15,781 feet high; Monte Rosa, 15,217 feet; and the Ortler, 12,814 feet; so that none of these mountains are equal to $\frac{1}{1717}$ of the average diameter of the earth. Hence, if this diameter be taken, for the sake of comparison, at thirteen feet, from 0·0787 to 0·1181 parts of an inch may be regarded as the average height of these excrescences on the surface of the terrestrial ball. In Fig. 18, which is a diagrammatic section of a portion of Switzerland, we see how comparatively little the Alps alter the curvature of the surface. From Bâle to

Fig. 18.—SECTION OF SWITZERLAND.

the crest of the Jura the curve is 1° 37′, while from Bâle to the crest of the Alps it is 1° 43′, so that the curve increases only from 1° to 2° in a length which may be taken as from $\frac{1}{50}$ to $\frac{1}{30}$.

The average crest height of the Andes, (11,713 feet) is greater by nearly one-half than that of the Alps (7,677 feet), and the crest height of the Himalayas (14,993 feet) is one-quarter greater than that of the Andes, while the heights of the Pyrenees are so small that they reach only the mean altitude of the Alps. In the Pyrenees the average crest height is 7,992 feet, which shows the dwarfish character of that range, as well as that of the Alps, with which it is comparable.

In the Old World the mountain chains run chiefly from east to west, the Alps, the Pyrenees, the Caucasus, and the Himalayas, being examples. In the New World the course is generally from north to south, the Rocky Mountains and the Andes being familiar types of the rule. Sometimes when, as in Western America, the plateau on which the Rocky Mountain system stands has been wrinkled by a series of broken ridges instead of one chain, we find a great number so wide apart that broad plains and basins lie between them, while in the heart of Europe the Bernese Oberland, the Pennine, Lepotine, Rhætic, and other ranges, form one great system or chain. Yet, as Dr. Archibald Geikie has observed in his clear exposition of these phenomena, while the general parallelism of any lateral offshoots is preserved, no single range may be observed for more than a comparatively short distance. After running for a few miles it "may be found to pass insensibly into another, while a third may be seen to begin on a slightly different line, and to continue with the same dominant trend until it in turn becomes confluent." The various ranges of the Alps, the Himalayas, and the Andes, are thus apt to assume an "arrangement *en échelon*." In these cases longitudinal valleys separate the different ridges, these depressions being very narrow in proportion to their length, while, in other instances, the ranges are trenched in a direction transverse to their trend by deep valleys. The valley of the Rhône, from its source down to Martigny, is a good example of the first class. The second order of valleys is illustrated by the Rhône also, in its course from Martigny to the Lake of Geneva. In many mountain ridges a pass or *col*—that is, a depression—connects the heads of two adjacent transverse valleys. These passes have for ages been of prime importance in the Alps, though some of the most famous ones are becoming of less value owing to the formation of the tunnels under them.

Most mountain ranges—the Alps, among others—show every sign of having been formed by successive upheavings and depressions during geological periods, the duration of which

it is impossible to even indicate with any approach to accuracy. The central portion of the chain is composed of gneiss, schists, granite, and other crystalline rocks, for the most part of very ancient date. The outline was formed by the wrinkling of the still-heated ball of the earth in primeval ages. On this mould were deposited, subsequent to its submergence, various strata, after which the youthful Alps were re-elevated into land. From the evidence supplied by the rocks which superimpose them, it seems that repeated uplifting and wearing-away followed, and that during comparatively recent geological times the mountains were again submerged, the grand upheaval, to which the present magnitude of the mountain is chiefly due, following this era in their history. "The older Tertiary rocks, previously horizontal under the sea, were raised up into mountain ridges more than 11,000 feet above the sea level, and, together with the older formations of the chain, were crumpled, dislocated, and inverted. So intense was the compression and shearing to which clays and sands were subjected that they were converted into hard crystalline rocks. It is strange to reflect that the enduring materials out of which so many of the mountains, cliffs, and pinnacles of the Alps have been formed are of no higher geological antiquity than the London Clay and other soft Eocene deposits of the south of England and the north of France and Belgium. At a later stage of Tertiary time renewed disturbance led to the destruction of the lakes in which the molasse had accumulated, and their thick sediments were thrust up into large mountain ranges, such as the Righi, Rossberg, and other prominent heights along the northern flank of the Alps. Since that great movement no paroxysm seems to have affected the Alpine region except the earthquakes, which from time to time show the process of mountain-making to be only suspended, or still slowly in progress." *

Mountains, indeed, have ever had an attraction for the geographer almost as great as they possess for the less-instructed lover of the mere picturesque. The one is content to accept results; the other attempts to analyse the causes which have produced these effects. Hence, as we have seen, the theories devised to account for their various phenomena have been more numerous than acceptable. Elie de Beaumont and Von Buch contended, for example, that all mountain chains of the same age have the same general direction. This assumption takes for granted that the earth's crust had been elevated at various periods "by forces acting at all places in parallel directions." Accordingly, about fifteen systems of elevation are distinguished in Europe. But we already know that such a generalisation must be very cautiously received, many mountains not having been reared by a single impulse, but by several acting at different periods. Nor have the elevations of any one epoch been effected in parallel and straight lines. At the same time, we may admit that in a broad way this theory has a basis of truth, and if inadmissible in detail, serves as a good foundation on which to raise a doctrine of mountain-building more in keeping with known facts. When this aspect of our subject comes to be considered, it will be found that the physical geographer has at his disposal materials for intelligent wonder even more ample than those on which the painter draws. The artist sees in the Alps only a confused sea of mountains gilded with the morning sun, or shot with the evening gold. He glories in the play of cloud effects, in the lakes glistening in the hollows, in the glaciers creeping through the valleys. But the geographer evolves order out of the apparent chaos, and finds his delight in studying the causes to which these phenomena are due.

The lofty mountain ranges, by deflecting winds which strike obliquely, have an important influence on the distribution of heat and moisture. For example, the west winds from the Pacific, on coming in contact with the coast ranges of California, are turned southward and become north winds. Finally, on leaving the attractive subject of mountains, it will be seen from the profiles (Figs. 20—23)

* Archibald Geikie: "Text-Book of Geology" (1885), p. 933; *Proceedings of the Royal Geographical Society*, (1879), pp. 422—443, and Edward Suess: "Die Entstehung der Alpen" (1875).

Fig. 19.—MONT BLANC (15,781 FEET), WITH THE GLACIER DU GÉANT.

(After a Photograph.)

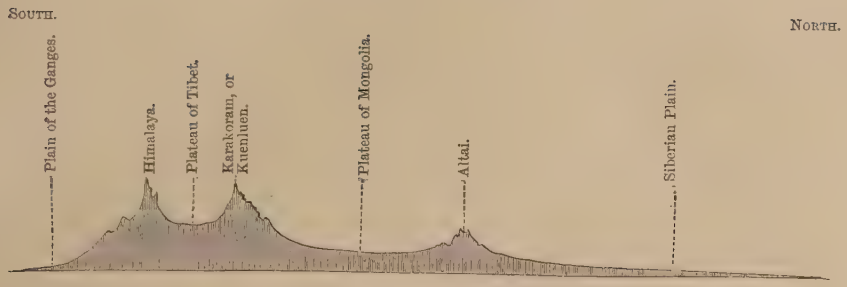


Fig. 20.—PROFILE OF ASIA.

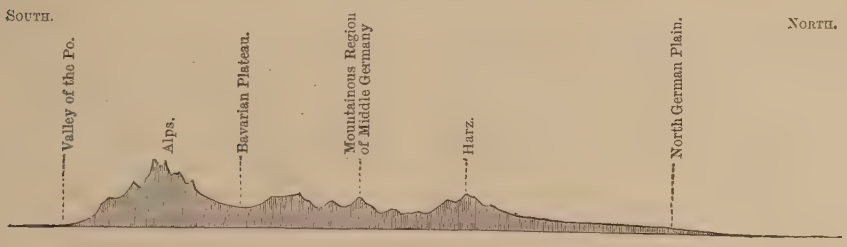


Fig. 21.—PROFILE OF EUROPE.

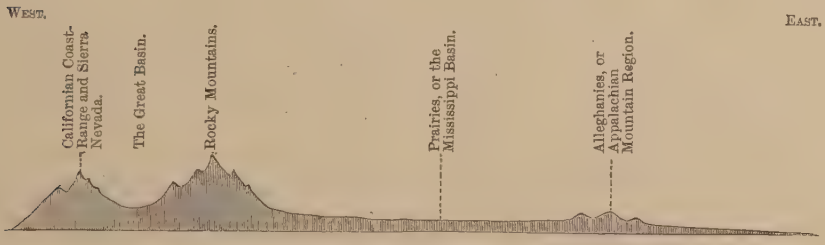


Fig. 22.—PROFILE OF NORTH AMERICA.

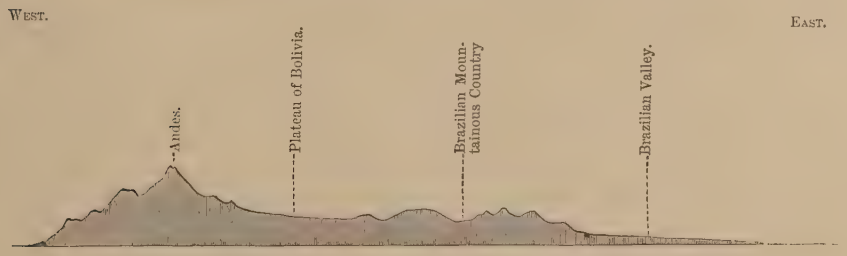


Fig. 23.—PROFILE OF SOUTH AMERICA.

of Asia, Europe, and America, that the Old and the New World present many analogies, if in the first the section is made from north to south, and in the other from east to west. But whether these remarkable likenesses are accidental—if we allow that in Nature there are any accidents—or are due to discernible causes to be sought for in the former history of the Earth, is a point on which it would be vain to speculate.

CHAPTER II.

The Earth's Crust: its Composition and Formation.

Arrangement of Rocks into Stratified and Unstratified—Mechanically-formed Rocks of various kinds—Miscellaneous Fragmental Rocks—Organically-formed Rocks, Limestones; Bath Brick, Tripoli, etc.; Guano; Coal; Peat; Asphalt; Bitumen, Petroleum—Chemically-formed Rocks—Various Forms.

When we cease examining the general contour of the globe, its hills and valleys, its seas and lands, and dig into the ground beneath our feet, we see that it is composed of various kinds of rocks. Some of them are soft beds of clay and sand, others are hard masses of granite, whinstone, and so forth, though all of them are, in the language of the geologist, "rocks." What is more, a very brief examination convinces us that some of these rocks are arranged in regular beds; while others are "without form," though, as they are often thrown up in beetling crags, and in the shape of masses obtruding through the bedded rocks, by no means "void." Again, on taking a still more minute survey, the intelligent student of the world in which he lives will in many cases notice that while the unbedded rocks—the granites, the whinstones, or traps and their kindred—are bare of life, the bedded or "stratified" ones are full of the remains of plants and animals which lived in former periods of the earth's history. In rocks which we learn to recognise as the oldest, these "fossils"—something "dug out," as the word means—are most widely dissimilar from anything now existing; while in those which are of comparatively recent date, the species approximate more and more to the forms now existing; and in the uppermost beds of all are species identical with the species now living in our seas and on the surface of the globe, though in most cases the distribution of the dead and living forms are widely different. Some rocks, indeed, like coal, many limestones, and chalk, are actually made up of the remains of plants or animals. We thus see that "the stony rocks are not eternal but the daughters of Time." Examining still more closely we discover that the bedded rocks have every evidence of having been laid down under the action of water, just as the mud at the bottom of a pool is deposited layer by layer by the water by which it is held in suspension. The heaviest materials sink first, the lightest fall last, and are therefore at the top. The materials entering into the composition of these rocks are also in many instances the same as those which make up the unbedded or "unstratified" ones, so that we are entitled to infer that the bedded rocks are formed by the wearing away by water of the unbedded ones, and that the former are therefore newer than the latter. Moreover, while in some instances we find that the beds are lying quite horizontal, just like the layers of clay at the bottom of a pond into which a muddy stream flows, in many other instances they are broken, thrown out of position, twisted, altered as if by great pressure and heat, and not unfrequently bent into an arch or absolutely turned upside down. We are consequently compelled to conclude that since they were laid down violent disturbances have been going on, and vast ages have elapsed, and as in many countries we see that the unbedded rocks have burst through the bedded ones, and formed wall-like masses or branches through their midst, the natural conclusion is that the disturbing agent has most frequently been those molten materials which form the foundation, as it were, of the world.

This much is evident to the least instructed eye. But on scrutinising still more closely the materials out of which the earth is composed with a view to study its story, we ascertain that the beds are not only of various

materials but of varied origin. They differ also as regards their texture. Some, for example, are masses like granite, others fissile or laminated like slate, others "schistose" like mica, others "oolitic," or "pisolitic" like Bath stone, others "amygdaloidal"—*i.e.*, with almond-shaped cavities filled with minerals. In some basalts we find these almond-shaped cavities; in others there is a slaggy or scoriaceous appearance, while in another series of rocks the beds seem of uneven texture, being made up of rounded or angular stones, all cemented together, but of very different origin.

Again, while some "rocks" are soft like sand or chalk, others are compact or granular, like many sandstones used for building purposes, while others are vitreous or flinty. They differ also, as we shall learn at a later stage of our studies, in the mineral materials out of which they are composed. In some mica predominates, in others silica or quartz, in many lime is the ruling substance, in a great many felspar and hornblende are the chief minerals, and in the vast beds of coal which form so important a portion of the earth's crust, carbon, in the shape of the remains of ancient masses of vegetation, is almost the sole ingredient.

However, no matter from what point of view they are studied, we find that all the materials entering into the ground beneath our feet may be conveniently divided into two great series: (1) Rocks which are arranged in *strata* or beds, and which have been derived by the wearing down of other rocks, and for the most part deposited in these layers by the action of water. Hence they are generally known as *stratified rocks*, or derivative, or aqueous, or Neptunian, from Neptune, the god of the sea. Some of the strata, except that they are consolidated by agencies which we may consider in the proper place, are little altered from the condition in which they were originally laid down. But several of the older formations are *metamorphosed*, or altered. (2) Rocks which are found, like granite or trap, in shapeless beds, without any trace of stratification or the influence of water. On the contrary, fire seems to have been the agent mainly at work in their formation and distribution through the earth's crust. Hence we call them *unstratified*, or igneous, or Plutonic rocks, Pluto being the god of fire. They also, like the stratified ones, are divisible into two minor sub-groups in accordance with the traces which they present of having been unaltered or altered since last the internal fire of the earth had been assorting them.

The Stratified Rocks.

These, though the newest, we may, for convenience sake, take first, as this mode of examination will enable us better to understand what follows when we begin to study the unstratified ones, which have played so leading a part in their formation and dislocation. We have already learned that there is evidence of these rocks not having all been formed in exactly the same way, though water has evidently been the prime agent in their disposition. A close inquiry conducted on

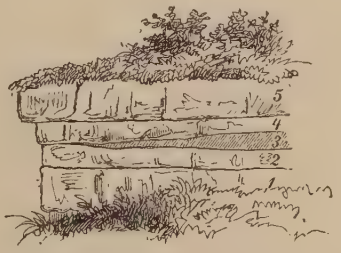


Fig. 24.—STRATA OVERLYING EACH OTHER.

The uppermost (5) is the newest, the age of the others being indicated by the order in which they lie, though a long period may have elapsed between the laying down of the two in immediate contiguity. Number 3 shows the "thinning out" of a bed, indicating that it had been laid down by a river, the deposit from which will necessarily not be so thick far out at sea as nearer its mouth.

these lines enables us to divide them into different groups, according to the apparent methods which have been at work in laying them down (Fig. 24).

Mechanically-formed Rocks.—The greater number of rocks have been formed by the wearing down of the igneous ones, and of course are younger than they; or by the destruction of other sedimentary strata formed in this fashion, after which these materials have been

transported by means of water to the place in which they are found in the shape of beds.

All the *Argillaceous*, or clay rocks, are of this nature. They are formed by the decomposition of rocks in which felspar formed a part, the impurities being fine sand, flakes of mica, and the remains of plants or animals. The purest kind of clay is white, and very plastic; but this property of clay is lost when the rock composed of it is subjected to great pressure, especially if accompanied by a high temperature. Hence, the highly plastic clays such as potter's or pipe clay, which is white and nearly pure, are of a more recent origin than those which are less fit for the potter's purpose. Fire-clay is nearly, if not quite, free from iron and alkalies, and contains much silica, or flinty matter, which, fusing under the action of heat, gives to the bricks made out of it a firmness which would otherwise be lacking. Carbon is also another ingredient, but, like silica, it is not found in quantities sufficient to prevent the bricks made out of it resisting the action of furnace heat. "Clinch" is a local name for a tough and more indurated clay. Loam is a soft and friable mixture of clay and sand, permeable by water, and much less plastic than clay. Mud and silt are the unconsolidated materials of some form of argillaceous rock, either clay, shale, or loam, as the case may be, and are commonly found in the beds of rivers, lakes, ponds, and similar situations. Marl is, again, a limey clay—a compound of clay and carbonate of lime, or carbonate of magnesia—which effervesces with acid, and when dry, cracks into cubical or rhomboidal fragments. It is commonly dug out of what have been the beds of ancient lakes, and owes its calcareous ingredients to the long, slow crumbling down of the shells of the fresh-water shell-fish which inhabit the water of these troughs in the earth's crust. When such a deposit contains less than fifty per cent. of clay it ceases to be a marl, and does not crumble on exposure to the air. It is then an "argillaceous limestone," or it may be micaceous, calcareous, dolomitic, or bituminous, according to the prevalence of certain substances. Shale is a laminated clay-rock, splitting into thin plates along the original lines of deposition. It passes into white clay, on one hand, and clay-slate on the other, but is usually more recent, geologically speaking, than true clay-slate. It constitutes a large proportion of the strata composing the Coal Measures, forming sometimes the base, or more frequently the roof, of a coal pit, and is the larger part of the refuse heaped up in great piles near the shafts of many collieries, where it is known by the name of metal, plate, bind, blaes, or blues, kilve, and so forth. Some shales are bituminous, and therefore closely resemble very impure coal, for which, in new countries especially, they are often mistaken. Others are carbonaceous, arenaceous, micaceous, or calcareous, according as they contain carbonaceous matter, sand, mica, or limey material. Clay-slate differs from the other argillaceous rocks in its cleavage structure, which renders it so valuable for roofing purposes. This it owes to the alteration or metamorphosis which it has undergone, and it may therefore be most fittingly described with the metamorphic rocks.

The *Arenaceous* or sandy rocks differ from the group described, in the fact that their constituents are either rounded pebbles or stones cemented together (conglomerate), angular fragments in this condition (breccia), uncompacted stones (gravel or shingle), compacted grains (sandstone), or loose grains (sand).

Conglomerate or pudding-stone forms vast beds in the earth's crust, and in California and other gold-mining regions, where it is known as cement, has been found rich in gold. The pebbles are of the most varied origin, and the rock which they unite to form is denominated a "granitic" or a "calcareous" —or any other—conglomerate, according to the predominance of any particular description of pebble or rolled stone in it. Very commonly quartz or some other flinty mineral or rock is the main material, and on that account conglomerates are usually very hard, and practically indestructible. The cementing material may be calcareous, silicious,

ferruginous, or a mixture of lime, flinty matter, or iron, the compactness of the pudding-stone varying according to the character of the cement. Sometimes it is so loose that the pebbles may be removed by mere pressure of the fingers. In other cases, it is easier to fracture the stones than the cement which binds them together, and in the cutting of such a rock the pebbles look like the raisins in a pudding. Hence the popular name applied to it.

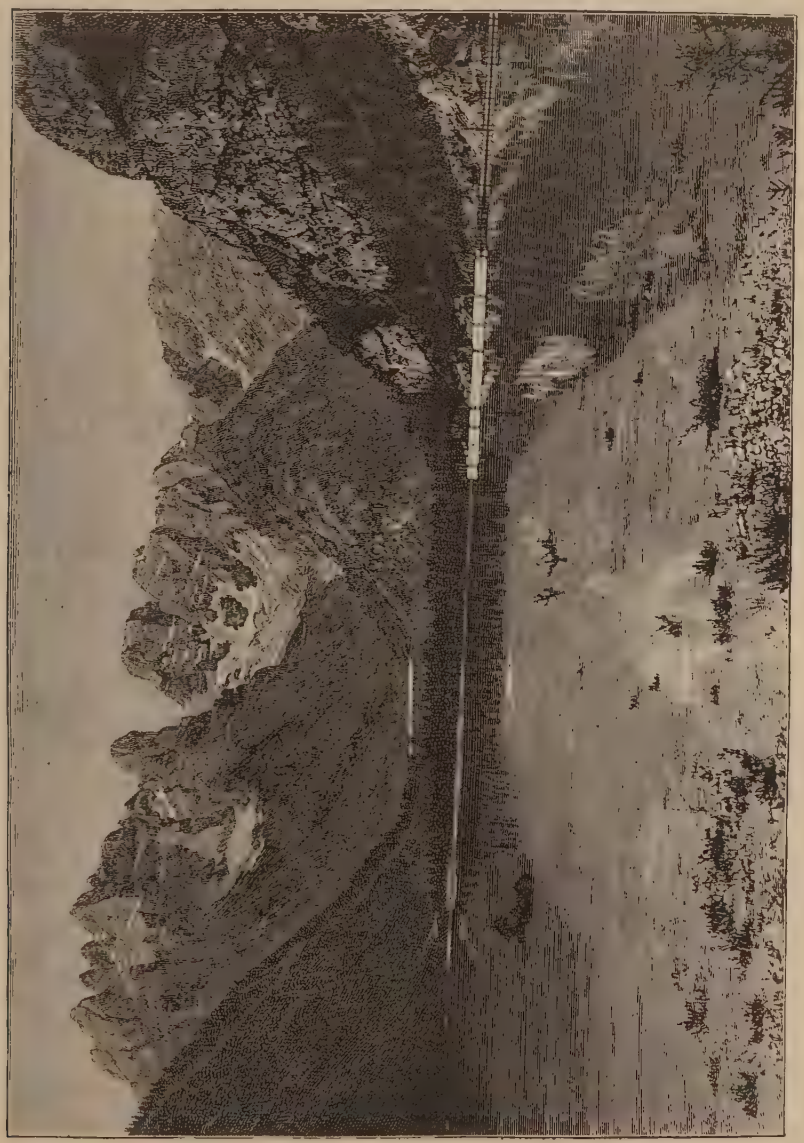


Fig. 25.—DÜREN LAKE AND MONTE CRISTALLO (DOLOMITE OF THE TRIAS), AMPEZZO VALLEY, SOUTH TYROL.
(After a Photograph.)

The grains in a bed of loose sand are usually of silica or quartz (the purest form of which is rock crystal), though sometimes felspar, limestone, dolomite, or other minerals, are the predominating materials in this form of "rock." A sandstone is, of course, simply sand cemented by some mineral substance, the character of the cement giving a name to the sandstone, and, combined with the pressure which it has originally undergone, imparting character to the rock. Again, according as the granules are large or small, the rock may vary from a fine-grained sandstone, like that of Craigleith, out of which most of the city of Edinburgh is built, to the "grits," in which the large grains of quartz being united by a hard silicious paste, constitute a stone extensively used for millstones all over the world. In brief, the difference between sand, sand-rock, sandstone, and grit, is simply one of degree, the one graduating into the other according to the size of the grains and the extent to which they are consolidated. In "flexible sandstone," the grains are so arranged as to stand apart, as if some ingredient had been removed by water percolating through the mass. In other forms, minute scales of mica are disseminated through the rock, so that if a thin slab is cut, it will bend backwards and forwards within certain moderate limits.

Miscellaneous fragmental Rocks.—There is a third class of mechanically-formed rocks, which cannot be classed under any of the foregoing heads. "Rubble" is, for example, an accumulation of angular fragments of various rocks indiscriminately thrown together. The pieces may be igneous or sedimentary, brought from a distance or derived from rocks in the immediate vicinity. They may have been swept down the current of a mountain torrent, or carried forward by a freshet or on an ice drift, or they may be the *débris* piled at the base of a wasting cliff or precipice in the shape of a "talus," such as often forms on the slope underneath the beetling crags of trap. Boulders, again, are large, water-worn, or at least rolled and rubbed blocks of stone, found on the soil amid surface material. These isolated masses are frequently of vast size, are in almost every instance brought from a great distance, and though at one time they were believed to have been swept before some hypothetical flood, it is now generally held that they have been dropped from icebergs, by which, in a former condition of the country, they had been detached from distant cliffs, and carried far from their original home.

Organically-formed Rocks.—These comprise the beds which are evidently derived from the decay of animal and vegetable matter, either wholly, or in great part, though most rocks of the stratified series containing as they do fossils, can claim to be more or less made of organic remains.

The *Limestones* are all comprised under the head organically-formed rocks. They are of varied colours, the principal ingredient in their composition being calcite, the colouring matter being oxide of iron, clay, carbon, and other impurities which have got mixed up with the lime derived from the worn-down shells, composed of material extracted from the sea in which the shell-fish lived. Some of these limestones are hard, and some crystalline, others are earthy-looking and soft, and between these extremes there are all gradations, some of them being characteristic of particular geological formations.

Thick and massive limestones exist of various colours (variegated marbles), which are much used in architecture. Beautiful marble is found to occur in the Alps, at Untersberg, near Salzburg (yellowish), near Ischl, Hallstatt, Adneth, and Hallein (mostly red marble), etc. This delicate marble is, as a rule, free from any admixture of clay, and from it is made lithographic stones, paving flags, etc. The whole world is supplied with its lithographic limestone from the quarries at Solenhofen and Eichstädt on the Altmühl in Bavaria.

Dolomite, a mixture of carbonate of lime and magnesia, is of a crystalline structure, leaky or cavernous, though its hardness is slightly higher than that of limestone.

Coarse dolomite (Fig. 25), in great irregular masses, may be seen in South Tyrol, where it makes picturesque mountains, and, in

another form, in the Rock of Gibraltar (Fig. 15).

Oolite is a limestone made up of minute spheroidal concretions, which look like the petrified roe of a fish; hence the name.* It is whitish or yellowish, easily worked, and therefore largely used as a building stone under the name of Caen stone, Bath stone, and Portland stone. Each grain, if examined microscopically, is found to consist of concentrated layers of carbonate of lime arranged around a central nucleus, which is generally a particle of sand. The theory of their formation is that this nucleus was kept in motion in a lake, or other enclosed area of water, thickly charged with carbonate of lime, until it got equally encrusted. If the grains are as large as peas, the rock into which they enter is termed "pisolite," while in Germany the term "Rogenstein" is applied to a rock in which the oolitic particles are cemented by a somewhat clayey matrix or intermediary substance. Pisolite is well developed at Carlsbad, where the substance of the grains tends to form into arragonite. In the hot baths at that place, the water is so charged with carbonate of lime that if small objects are suspended in it they will soon get covered in the same way as the nucleus of the oolitic or pisolite grains did. It may be added that dolomitic pisolite, with large grains sometimes of magnesite, may be noted in the serpentine of Zebce, at Bosna, in Bosnia.

Silicious limestones contain silica. These limestones are therefore harder than ordinary limestones, and, on decomposition of the calcareous matter, leave a flinty residuum, which is known as the "rotten-stone" of commerce.

"Bath Brick" is manufactured at Bridgewater from a tidal deposit of silicious silt, from the River Parret, in Somersetshire, at the junction of the fresh and salt waters. Its peculiar properties are probably owing to the flinty cases of minute animalculæ, destroyed by the salt tidal water when it meets the fresh water of the river; and masses of rock, such as the Tripoli or polishing slate, etc., are made up of the microscopic valves of plants called diatoms. "Bergmehl," or mountain meal, used by the natives of Finland and Lapland to mix with flour in times of scarcity, is of this nature, though it is perhaps needless to add it has no nutritive properties whatever. At Bilin, in Bohemia, there is a bed of "Tripoli"† 14 feet thick, which is used for polishing stones and metals, and in the Kawsoh Mountains, in Nevada, United States, there is a deposit 250 feet deep, some of the beds being 8 to 10 feet thick, and so full of these flinty-cased diatoms, that the substance contains nearly 90 per cent. of silica.

Chalk, which will be considered when the formation of that name (the Cretaceous) comes to be described, is also an organically-formed rock, the grains being, for the most part, the minute shells of the microscopic animals called foraminifera, which fell to the bottom of the sea in former periods of the earth's history, until they formed great beds, as indeed their modern representatives are slowly doing.

The mountain limestone, so generally associated with the coal beds, is, in many cases, so full of the stems of fossil stalked-star-fishes, or encrinites, and other animals, that it may be regarded as almost wholly composed of organic matter cemented together with a little impure lime derived from the same source.

The Kelloway Rock is a sandy limestone, from three to five feet thick, abounding in fossil shells, indeed in most cases almost entirely made up of them, and so called from being well developed at Kelloway Bridge, in Wiltshire.

In the fossiliferous limestones of the Paris *calcaire* we see a repetition of the Leitha chalk of the Vienna basin. There are two chief varieties of this limestone. One—Lithothamnium chalk—contains the remains of the coralline seaweed peculiar to this formation (*Lithothamnium ramosissimum*, Reuss), with the shells of mollusca. This is found in the quarries at Wöllersdorf and Brunn, near Steinfeld, in the Leitha mountains near Mannersdorf,

* *Oön*, Greek for an egg.

† It derives this name from having been originally obtained from the Turkish province of that name, in Northern Africa.

and in the imperial quarries near Zogelsdorf, at the side of the Bohemian and Moravian "massifs." The other—the Amphistegina chalk with shells of foraminifera, especially of the *Amphistegina Haueri* of D'Orbigny—is more solid than the Lithothamnian limestone, and is found in the quarries of St. Margaret on the Neusiedl Lake, near Loretto, in the Leitha Mountains, etc.

The Bone Beds, or Coprolite * deposits are strata, mainly clay and calcareous shales, composed of phosphate and carbonate of lime, as in the Gault and Cambridge green-sands, or, as in the Ludlow Bone Bed and the Lias Bone Bed, composed of the remains of reptiles and fish, either compressed into a rock or, as in so many caverns, covered by stalagmite, or the droppings from limestone, and more or less mixed with earth or sand. Coprolites are the accumulated excrement of animals mixed with the remains of bones, teeth, scales, etc. In Canada, various parts of the Southern States such as South Carolina, Swabia, France, Thuringia, and in England, at the junction of the Rhætic and Lias formations, these coprolites are dug for the purpose of being manufactured into manure, their value depending on the phosphate of lime which enters so largely into their composition.

Guano, a word derived from the old Peruvian word Huano, meaning bird dung, is composed of the droppings of sea-fowl †—penguins, gannets, cormorants, divers, gulls, terns—and mixed with the bodily remains of birds and seals. The most important beds of guano are found on the coast of Peru, between 2° and 21° south latitude. The centre of the guano deposit is—or was, for it is all but used up—in the Chincha Islands (Fig. 26), bare rocks rising out of the sea and covered with beds of guano which were in places 200 feet deep. From this group alone 7,000,000 tons, worth about £80,000,000, have been exported. For years, indeed, Peru throve on this national wealth, and to the listlessness engendered of the idea that a nation could exist without feeling the responsibilities of government, this unhappy state owes many of the troubles which in time overtook her. All that the Peruvians did was to authorise the digging of the guano, and to draw on the proceeds. The work was chiefly done by Chinamen, and as the ammoniacal fumes injured the eyes of the workmen, it is hard to imagine labour more toilsome or less grateful than shovelling the garnered ordure of generations of sea-fowl into the holds of the guano ships. The Chincha deposits were nearly exhausted several years ago, and the little that still remains on other islands along the Peruvian coast is being rapidly denuded, though the estimates as to the amount still remaining are so contradictory that it is needless to repeat them. Peruvian guano is especially rich in phosphate of lime, derived from organic remains and ammoniacal salts. Guano is found also—among other places—on the east coast of Patagonia and on the coral reefs of Baker's, Malden, Howlands, and Jarvis' Islands, in the Pacific Ocean.

There is only one reason why guano does not accumulate in other latitudes quite as much as in those named. The cliffs of the Arctic regions, and of the northern and western islands of Scotland, not to mention such haunts of birds as the Bass Rock and Ailsa Craig, are, for a large portion of the year, white with myriads of sea birds; but their droppings never form more than a thin layer, the frequent rains washing it away. Hence, for the formation of thick beds of guano such as those described, a rainless or, at least, extremely dry climate is essential, and this is exactly what prevails in the regions mentioned. The lower part of Peru is proverbially dry. In the town of Iquique a slight shower falls not much oftener than once or twice in many years, and as three-fourths of the constituents of guano are soluble in cold water, the very circumstances which make it valuable as a plant food would render it impossible of accumulation in a wet region. Patagonian guano contains much less ammonia ($2\frac{1}{2}$ per cent.), but it has 47 per cent. of phosphates, while the guano of Sombrero, one of the West

* *Kopros*, Greek for excrement.

† A fuller description of this valuable material will be found in the "Countries of the World," Vol. III., pp. 304—309.

Fig. 26.—THE GUANO BEDS ON THE CHINCHA ISLANDS, PERU.

Indian islands, is purely phosphatic. The entire island is composed of this "sombrerite," which consists wholly of the bones of turtles and other marine animals, coral fragments, &c., which have been cemented into a more or less solid mass by the dissolved droppings of birds. It is used for the manufacture of artificial manure, and if the deposit holds out, there is little doubt that the entire island will in time be removed. The guano of Malden Island, in the Pacific, is also very rich in phosphate of lime; and in the caves haunted by bats in Arkansas, Texas, and the Bahama Islands, considerable deposits of guano have been discovered, though, owing to the animals depositing it not being fish-eaters, and, in some cases, not even flesh-feeders, the manure obtained from these localities is by no means so rich as that already described.

But of all the organically-formed rocks, the most important are those which constitute the *Coal beds*. They are, for the most part, the products of vegetable accumulations, are notoriously combustible, and vary from a brown to a black colour. Mineral coal is essentially carbon combined most frequently with bitumen or some kind of bituminous substance and more or less earth, which is what is known as the ash that remains behind after the coal is burnt. The difference in composition and texture exhibited by the many varieties is owing to the degree of metamorphism of the original substance.*

The first trace of coal is the "black olonezer earth," in the Huronian clay slates (phyllites) on the north-west shores of Lake Onega. According to the account given by Inostranseff, the first variety of this coal is of a black colour, with diamond-like metallic appearance, and consisting of:—

Carbon	90·50
Hydrogen	0·40
Nitrogen	0·41
Water	7·76
	99·07

Anthracite is coal of a very ancient date, some varieties of which pass into graphite, better known as the "black lead" of pencils, though in reality it is simply carbon. It is hard, dark, lustrous, does not soil the hands, and breaks with an irregular, somewhat rounded fracture known as conchoidal, from a fancied resemblance to the curved outline of a shell (*concha*). There are several varieties of it—the chief of which is common anthracite, which produces little flame, does not soil the hands, and burns without smoke; it is superior to any other description of coal for heating purposes. The largest deposits of it are in North America, in the states of Pennsylvania and Rhode Island; it also occurs in South Wales; in England; near Mons; in the Tarantaise; on the Harz; at Landshut, in Silesia; and at Schönfeld, in Saxony. Extensive anthracite deposits also occur in China.

Carbonite, bituminous, or carboniferous coal is black, and soils the hands easily. It contains 75 to 85 per cent. of carbon, with 10 to 16 per cent. of bituminous matter,† and burns with a light flame. The varieties of this coal are *glance coal*, which is full of shale; *pitch coal*, with a bituminous lustre, brittle, light, and a conchoidal fracture; and *fan coal*, or *sooty coal*, which is less bituminous, with fragments of wood. The characteristics of coal of these descriptions are manifest, but with regard to glance coal we see that its formation has been effected by constant eruptions, and that many portions of shale have been intercalated with it. No coal is so generally useful as this glance coal, which is capable of being used for various purposes, and gives out, on the whole, nearly as much heat as any other variety.

Cannel coal, or candle coal, so called from its bright flame, is a highly bituminous mineral coal. It has a waxy lustre, and deep black colour; it is not brittle, but splits easily. Specimens of this coal, which are susceptible of a high polish, are found at Wigan, in Lancashire, and Clee Hills, in Shropshire; and in deposits of the coal on the Ruhr; in Bohemia, in France, Russia, and Tasmania.‡ The light

* A description of the formation of coal will be given at a later stage of our studies.

† Though in reality there is nothing approaching true bitumen in the so-called "bituminous coals," the term is, however, universally employed.

‡ The jet found in Whitby and Spain is a hard variety of cannel coal.

produced from cannel coal is of a very high quality. Hence it is extensively employed for gas-making. The greatest depth of black coal is to be found in the anthracite or Coal Measures, and especially in the Carboniferous formation. The most important carboniferous formations in Austro-Hungary are in Bohemia, in the large coal basin of Schlan-Rakonitz, and at Pilsen, in the Schatzler coal district, and especially in Prussian Silesia and Moravia, in the Ostrau basin, which is one of the largest coal basins known, and also in the vicinity of Jaworzno, in the district of Cracow. Bituminous coal is found at Funfkirchen and at Steierdorf, and at numerous places at the northern foot of the Alps. The three great coal basins of Germany are the upper Silesian coal basin, the Saar coal basin, and the coal mines on the Ruhr. The best coal deposits in Europe are the English. Of these, the greatest is that of South Wales. The Forest of Dean is an outlying portion of this field. North of the Malvern Hills is a straggling patch of coal measures known as the Severn Valley coal fields. The South Staffordshire, the Tamworth, the Leicestershire, the Derbyshire and Yorkshire, the North Staffordshire, the Lancashire, and the Northumberland and Durham fields, are all more or less important. The Cumberland, the Denbigh and Flintshire, the Cheshire, the Anglesea, and the Somersetshire, are the remaining areas in England. In Scotland, the Ayrshire, the Lanarkshire, the Stirlingshire, the Midlothian, and the Fifeshire, are the principal fields. In Ireland, the only beds worked are those of Castlecomer, near Kilkenny, and another between Tralee, Mallow, and Killarney; in the north there is a small basin in Coal Island, but it is partly covered by New Red Sandstone strata.

A large coal basin exists in North America, where the coal fields extend over an enormous area, greater than that of the German Empire, and, it is unnecessary to say, infinitely more extensive than that of England. The Appalachian coal field alone covers about 60,000 square miles. The Illinois and Missouri basin is estimated to cover an area quite as large, and not to mention many smaller fields in the United States and Canada, there is, in Michigan, a series of coal measures extending over 5,000 square miles.

In China there are also enormous coal fields at present almost untouched. Near Pekin the beds which supply the city with fuel are ninety-five feet thick, and on the west and north-west, south of the great mountain range which stretches across northern China, the area of the carboniferous strata is believed to exceed 100,000 square miles. In India, Japan, Borneo, Labuan, and elsewhere, coal beds are found in greater or less abundance, and in Australia they extend with short intervals from Bass Strait to the Gulf of Carpentaria, the principal mines being near Newcastle, in New South Wales. In New Zealand there are also deposits; and in various parts of South America, particularly Brazil and Chili, seams have been discovered and worked.

Brown coal is of a newer date. It is black or brownish-black, highly bituminous, with the vegetable texture so well preserved that its origin is at once observable. It is not quite so black as the other coals, gives a brown streak, and contains 44 to 75 per cent. of carbon, leaving a large proportion of ash when burned. It burns freely, with a long reddish flame, and is found in several varieties, the chief of which are:—A black, brittle form, with a vitreous lustre, not variegated, of which the "Salon" coal of Germany is an example; deep (Pech) coal, deep black, brittle, and exhibiting a longitudinal lustre; common brown coal, that is much mixed with lignite, blackish-brown, with foliations, and a greasy lustre; lignite, woody brown coal of a brown colour and streak, containing 44 to 57 per cent. of carbon, the proportion of ash being generally very high, and the structure of the mineral indicating a woody texture. Most of this lignite has been derived from the wood of conifers. Indeed, wood under pressure has in the course of two or three centuries been converted into a substance so like lignite as to be practically undistinguishable. In Germany the brown coal is found at Cologne, Zittau, and other places. In Austro-Hungary glance coal is found at Salesl, near Aussig, in Bohemia;

at Leoben and Eibiswald, in Styria; and at Trifail, in Carinthia. Deep coal occurs at Häring, in Tyrol, in the mines in southern Bavaria, and along the north of the Alpine range, and there are mixtures of brown coal and deep coal in the beds of Saaz and Falkenau, in Bohemia. Lignite is found in the Köflach basin of Styria and the Wolfsegg basin of Upper Austria, etc. All these formations belong to the Tertiary epoch.

Peat, or *turf*, may be regarded as the newest of the Coal formations. It is, in fact, coal in process of development, consisting of plants which have died and formed layer after layer, until the result has been a compact felted mass, brown and combustible, often mixed up with the trunks of trees which grew on the site, and with the bones of animals which either fell in the ancient forest or were mired in the swamp which took its place.

Sometimes the species have so decayed that no trace of the original outline can be detected. In others it is easy to identify the particular mosses or other plants which have entered into the composition of the turf. In various places a kind of humus or soil is forming, especially where sand or clay has got mixed up with the turf. "Deep turf" is usually a black, compact mass, which is characteristic of the lower portion of the turf beds, and has been produced by the slow deposition of vegetable matter, combined with the pressure of the overlying masses. What the Germans call "speck-torf," is structureless—that is, it does not exhibit a structure divisible into layers.

Bedded turf, on the contrary, is composed of plant remains and analogous substances, is of light or reddish-brown colour, and exhibits a well-marked stratification. Turf has received various names, indicative of the plant from which it is derived, such as moss-turf, grass-turf, heath-turf, wood-turf, etc.

The laws governing the formation of these great bogs are now tolerably well known. Peat, as we have seen, is made up simply of water-plants which have decayed in swamps undrained and undisturbed through a long course of years, though not unfrequently its accumulation is, in part, due to forests which have been felled or have fallen, and been allowed to lie rotting under like conditions. It is thus coal in an early stage of consolidation, just as lignite is vegetation further advanced in the process of carbonification. Sometimes, indeed, the peat, under favourable circumstances, forms so rapidly that the species of plants entering into its composition can be readily detected. For instance, at Alt-Warmbrüch Moor, near Hanover,* the turf reformed in fifty years, and in thirty years more had attained a thickness of from three to four feet; and much the same observation has been made at Franzensbad, near Eger. In the valley of the Somme three feet of peat are affirmed to have grown in from thirty to forty years, while in the colder climate of Denmark it is reckoned that not more than ten feet have accumulated in nearly three centuries.

The peat mosses of Europe have afforded the geologist excellent opportunities for obtaining data regarding the formation of "superficial deposits," while the antiquary, as has been so admirably demonstrated by the researches of Steenstrup and Englehardt in Denmark, has been enabled to almost recover certain sections of unwritten history from the objects preserved in the peat. A wooden bridge, constructed, as the inscription showed, by Germanicus during the German War, about A.D. 16, was excavated from beneath a bed of peat; and in Galway a hut and a paved passage were found under thirty feet of turf, demonstrating, of course, that at the period when these were built habitable ground existed on the spot. Roman roads covered by eight feet of peat are known to the archæologist; and out of the Dutch mosses there have been disinterred boats laden with bricks; while canoes with stone weapons are among the most frequent "finds." In 1833, a house built of oak beams, and evidently—from the contemporaneous tools—of the Stone period, was brought to light in Drumkilen Bog, in Donegal; and among the most interesting results of modern discovery is the curious succession of forests which can be traced in the Danish "mosses." The lowest zone of peat contains remains of

* Tate: "Physical Geology," p. 99.

the Scotch fir, while the upper is marked by the occurrence of the oak. Yet the Scotch fir has never been known as a tree indigenous to Denmark; and the oak, which took its place, has in turn been replaced by the beech. In the older part of the peat stone implements are embedded, while in the later portions the works of art are bronzes. A long time must, therefore, have elapsed between the date when the first and the last implements were lost in Aberdeenshire, is, for example, full of trunks immersed in peat. Peat has already formed in the Wood of Drumlanrig, levelled so lately as 1756; and the moss of Kincardine, in the upper part of the Forth Valley, owes its existence to the dense oak forest which at one time covered its site. In 1651 an extensive forest of dead fir-trees existed in Western Ross-shire; by the year 1666 a moss occupied the site of the fallen wood; and in the year 1699 peat was

Fig. 27.—THE IRISH ELK (*Megaceros hibernicus*).

the forest now converted into turf—evidence, if evidence were needed, of the danger of hasty conclusions regarding the age of any one bog from data obtained by the study of another.

The remains of the Irish elk (Fig. 27), wild ox, bear, beaver, red deer, and man, which have been found in so many peat deposits, demonstrate the condition of the country prior to their formation. We know, indeed, that several modern bogs are due to the destruction and decay of forests, aided by the accumulation of water in the hollow ground where the timber was allowed to lie. The Forest of Mar, in regularly cut out of the bog then formed. The primeval forests of Hircania, Ardennes, and Semana, were destroyed by Severus on account of their harbouring the "Barbarians," and several in Britain were felled by order of Parliament because they sheltered wolves and outlaws. Again, the Welsh, in the reign of Edward I., cut or burnt down many of their woods, as the Irish did in the time of Henry II., for the purpose of harassing their invaders; and in other districts huge trees, in good preservation, and with the marks of the axe still visible on their trunks, are frequently dug up.

Some of the Scottish mosses date from the time of the Roman invasions, and were the consequence of it. The marks of the narrow chisel-like Roman axe have been detected in many instances in the lower tier of stumps over which the peat has accumulated, and in some cases the axe itself has been found sticking in the buried tree. In Pousil Moss, near Glasgow, a leathern bag containing about 200 Roman silver coins was found, and in Annan Moss, near the Roman Causeway, a Roman ornament of pure gold was disinterred. A Roman camp-kettle was found eight feet deep under a moss on the estate of Ochtertyre. A Roman jug was taken out of Locher Moss, Dumfriesshire; and, not to enumerate many similar finds, two bronze vessels were dug up in the Moss of Glenderhill, in Strathaven. The legionaries cut down wide avenues in the forests through which they marched. "The felled wood was allowed to rot on the surface; small streams were choked up in the levels; pools formed in the hollows; the soil beneath, shut out from the light and air, became unfitted to produce its former vegetation; but a new order of plants, the thick water mosses, began to spring up; one generation budded and decayed over the ruins of another; and what had been an overturned forest became in the course of years a deep morass—an unsightly but permanent monument of the formidable invader!" Hurricanes might have accomplished a similar work of destruction; the trees in some of the Scottish mosses being either turned up by the roots, or broken across, and lying all one way. *

It has even been asserted by some antiquaries that few of the British bogs are older than the Roman period. This is, probably, a too sweeping conclusion, for some of the objects found in them may have been entombed long after the peat had been formed. In 1542 a troop of English cavalry pursuing the routed Scots across the Solway Moss, were swallowed up, and to this day the turf-cutter comes upon their skeletons and armour. On the other hand, in a turbary off Loch Moira, under eleven feet of peat and one foot of gravel, a skeleton, completely clothed in hair garments, was discovered. Now, as wool was early used in Ireland, the remains thus clad must have been of a very ancient date.

On the Continent turf formation is said to be rare on calcareous, and frequent on silicious bottoms, though in Ireland the rule does not hold true, probably owing to local circumstances not permitting of the water draining away as easily as it does in a limestone country generally. It even occurs, according to Portlock, on the summit of some high hills, where a clay bottom retains the moisture. The growth of bog moss being greatest in the centre of a depression, where moisture is most abundant, bogs are usually much swollen in the middle, and go on increasing till the slope is sufficient to discharge the water, and limit the growth. Examples are cited, by the writer named, where towns once visible from each other, are now shut out from view by the elevation of a turf moss between them.

Such bogs are liable to overflow after long-continued rains. In Ireland, where about one-seventh of the country is covered with bogs—that of Allen being 238,500 acres in extent, and in many places more than thirty feet in depth—such mishaps are by no means unfrequent. In January, 1883, after a heavy downfall of rain, several thousand acres in the vicinity of Castlerea were submerged by the "bursting" of the neighbouring bogs. Mills were stopped, bridges choked, fields covered to the depth of twenty-six feet, and traffic on the road between Bellingare and Castlerea was suspended by the overflow of a moss, flooded by the rain until it had broken its bounds, and began advancing rapidly towards the town. The bog at Baslick, which "moved" some time before, also broke up in several places, and threatened to begin its march on the arable country in the neighbouring lowlands. Such mishaps are, unfortunately, too common in Ireland. In June, 1882, a large bog on the Wistropp Estate, in East Clare, began to crawl

* Miller: "Sketch Book," pp. 8–9. A fully illustrated account of turf and its geological relations will be found in Professor Rupert Jones's paper in "Science for All," Vol. II., pp. 341—348.

to the south-eastward, carrying before it several patches of reclaimed land planted with potatoes, and destroying a portion of the main road to Limerick. A few years ago some labourers, working in a field in Galway, heard "a noise like thunder," followed almost immediately, to use their phrase, by "the country rolling upon them," in the shape of the black ooze of a "moving bog." By-and-by the witnesses of this strange sight were driven from the field which they were cultivating; and before the lava-like stream ceased its progress, two cornfields, a potato patch, and a considerable tract of pasture land was inundated. The bursting of the Solway Moss, more than a century ago, is a case even more familiar; for this vast morass, saturated by unprecedentedly heavy rains, left its bed and covered four hundred acres of farms to such a depth that several cottages were buried, and a number of others so far entombed that their roofs alone appeared above the dreary expanse of liquid peat. When the inundation ceased, it was found that the original level of the bog had in its own area sunk twenty-five feet, and that, in the lowest ground which it had invaded, fifteen feet of turfy substance had been deposited. Again, in 1831, a bog of one hundred acres, between Bloomfield and Geevah, in Sligo, burst, and, in addition to covering a large extent of arable land, cut up the ground into deep ravines, and carried away the road from Bloomfield to St. James's Well, for a distance of 9,200 yards.

In other parts of Ireland the furrows of what were once ploughed fields have been found underlying bogs, and in Donegal, the remains of an ancient plough and the wattles of a hedge were discovered six feet below the surface, which, like the house in Drumkilen Bog already referred to (p. 60), were overwhelmed by some such catastrophe, though history is silent regarding the event. In all peat bogs there is a considerable amount of iron, or limonite, formed either by diatoms, or derived from the decomposition of the iron pyrites, and which assists in the preservation, in a black, hardened form, of the oak buried in the turf.

The reclamation of peat bogs has always had keen interest for the speculative land improver, though his success has rarely been sufficient to account for the enthusiasm which the subject has evoked. In Scotland and Ireland small tracts have been recovered: but all the world knows the fate of Mr. Roscoe, who, after displaying his sagacity as a statesman and historian, wrecked his fortune and his reputation for shrewdness in trying to make a farm out of Chat Moss. Even the Bog of Allen has had attractions for dreamers over this description of Herculean labour. Sometimes the upland "moss scalps" or "hags" shrink and dry up, by the water "seeping away;" and occasionally it is possible during the summer months to evacuate them by cutting trenches, through which the black ooze drains. But wise men leave peat bogs alone as objects for agricultural experiment, though as materials for the instruction of the geologist and the physical geographer they are worthy of even more space than can be bestowed on them.

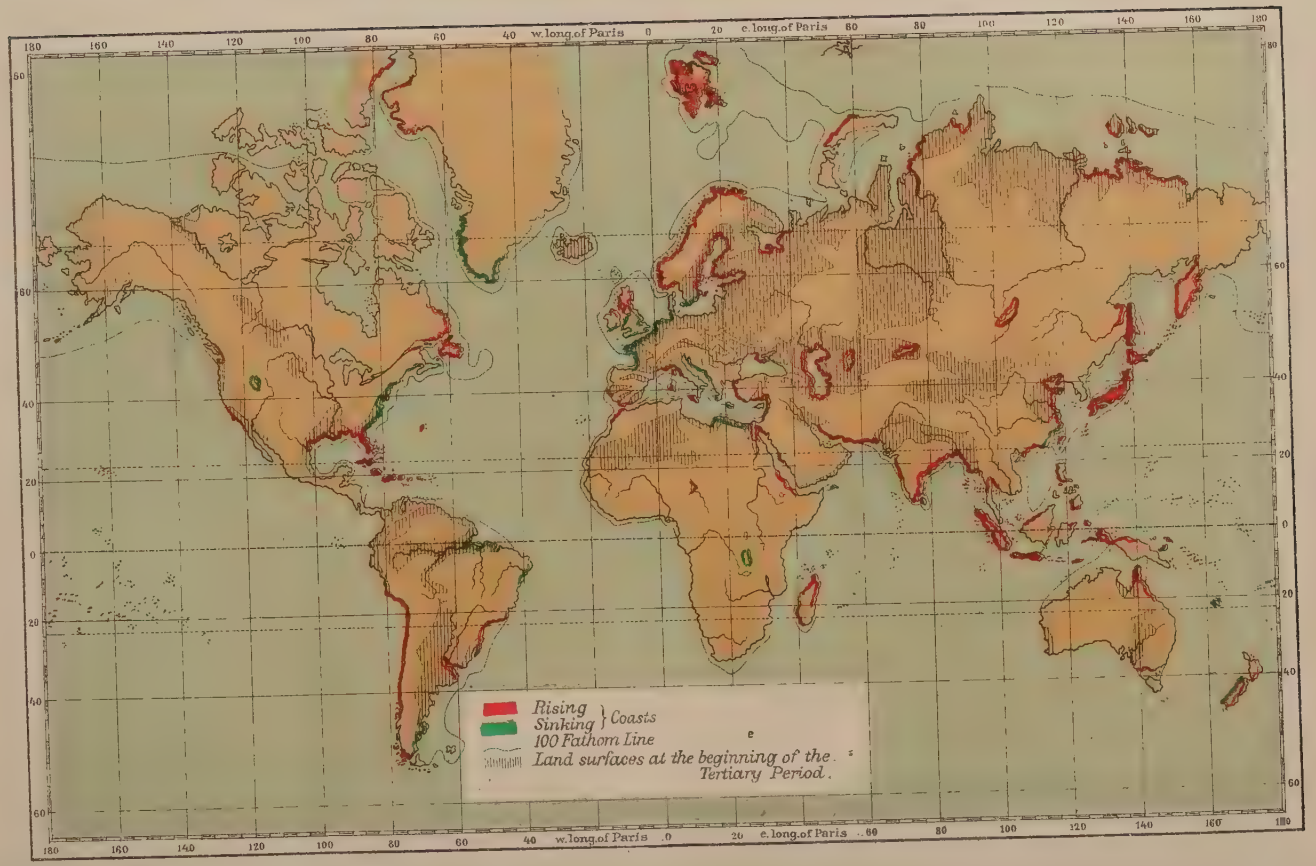
Asphalt, or *bitumen*, is a black or brownish-black substance, which, when at its firmest, is not unlike coal, and breaks with a bright conchoidal fracture, but at its softest it is a thick, viscid, tar-like mass. It melts at a low temperature (212°, the boiling-point of water), and burns with a reddish smoky flame. It is due to the decomposition of animal and vegetable matter, and may be regarded as one of four changes which, under certain conditions, organised matter undergoes. The first is in being converted into naphtha, the second results in petroleum, the third in mineral tar, and the fourth is this asphalt—the whole of these four substances merging by invisible degrees into each other, and being probably of the same chemical composition. Naphtha in some localities flows out of the earth in a clear, colourless stream. When it takes up oxygen from the air, it becomes brown and thick, and is known as petroleum, which is only limpid after purification. Further oxidation and evaporation convert it into mineral tar, and by-and-by asphalt is the final result of the chemical changes going on.

As a "rock," in the geological sense, asphalt is found in many parts of the world, and though not characteristic of any particular period, it exists in the older formations in a state of the greatest purity. Considerable quantities are obtained from Cuba, under the name of "Chapapote," or Mexican asphalt; and that of Caxitambo, in Peru, is noted for its purity and high lustre. In this country it appears, as in West Lothian, in the joints of sandstone, and is no doubt due to the destructive distillation of the associated coals and coaly shales by intrusive igneous rocks. In the flagstones of Orkney and Caithness its presence may probably be traced to the decay of the ancient fishes which are found so abundantly in these rocks. But it is in the West Indian Island of Trinidad where asphalt appears in the greatest abundance. The "Pitch Lake" is 99 acres in extent, and of unknown depth. Coursing over the surface are numerous rivulets, and every now and again the asphalt wells up in a soft condition, accompanied with a discharge of sulphuretted hydrogen gas. These viscous emissions, however, soon harden by exposure to the air, and, like the rest of the lake's surface, become hard enough for any one to walk across it. In the neighbouring country there are also detached patches of asphalt, and the fragments cast upon the adjoining shore are proofs that at certain points the sheets protrude under the sea. South of Cape La Brea is a submarine volcano, which occasionally boils up and discharges a quantity of petroleum. On the east side of the island there is another, which throws masses of asphalt upon the contiguous shore. The Pitch Lake does not, however, seem to have been much disturbed in modern times. Throughout its circumference of one mile and a half it is firm enough to bear a waggon, though still somewhat plastic, and appears to be in motion towards several points which act as vortices, as the trunks of trees disappear and emerge at some distance from the point at which they sink. It seems also to have subterranean communication with the sea. Yet small fresh-water lakes and streams swarming with fishes are distributed over the surface, with numerous islands abounding in tropical verdure.* The name "asphalt" is derived from the "Lacus Asphaltites," or Dead Sea, and, like the "bitumen of Judæa," another common designation for this subject, expresses the popular idea of its origin. In reality very little is now found near the Dead Sea, though the Fountains of Is, from which ancient Babylon was supplied, still yield all that is required by the inhabitants of that region. Asphalt stone, a porous Secondary and Tertiary limestone—found in large quantities near the Val de Travers, in Switzerland; in the neighbourhood of Syssel, in France; in Lobsau, in Alsace; in Limmer, near Hanover, and at Holle, in Holstein—is even more valuable It derives its name from the fact of its being impregnated with asphalt to such an extent that it is extensively used for pavements and other places where dryness is a desideratum.

Ozokerite, or mineral wax, is red or greenish-yellow, and is extensively used for the manufacture of candles. It is another form of the series to which asphalt belongs, and is abundant in some parts of Galicia, near Drohobycz and Boryslav for example.

Petroleum is a much more important development of the same order of "hydrocarbons," and is even more extensively distributed, though the deposits at Baku, near the Caspian, and in Pennsylvania, United States, are those which are greatest in extent and most widely known. Though known in the latter region for many years, it was not until the year 1859 that its pumping took anything like active shape. Then crowds of adventurers began boring, cities rose like mushrooms, and in the course of a few years or months immense fortunes were made or lost by those who had "struck oil," or had failed to "strike" it, or whose wells ran dry as suddenly as they had begun to flow. Petroleum occurs in all geological formations from the oldest to the newest,

* Peckam's "Monograph on Petroleum and its Products," in the *Tenth Census of the United States*, Vol X. (1884), is a treatise practically exhaustive of the subject. See also the works of Humboldt, Verteuil, Gumilla, Alexander, Sainte-Claire Deville, and Wall; and, for an account of the Pitch Lake, the graphic description in Kingsley's "At Last: A Christmas in the West Indies" (1874).



REGION OF SECULAR RISING AND SINKING

(AFTER DARWIN, CREDNER, AND OTHERS).

though its principal development is in the Silurian and the lower half of the Tertiary. The origin of these vast subterranean tanks of oil can only be inferred, since there is nothing in the structure of petroleum to afford a clue to the source from whence it is obtained. It is, however, almost certain that it is of organic origin, few chemists of much eminence now holding the hypothesis that it owes its presence to chemical action. Before the American wells were opened up, considerable quantities of petroleum and its allied products were distilled from bituminous shales, including the famous "Torbanhill mineral," the organic matter in these shales being chiefly vegetable. It is, therefore, all but proved, from the long series of experiments undertaken, that petroleum is not a chemical product in the sense that it can be renewed in the localities from whence it is being pumped, but an outcome of distillation going on in the earth's crust. If so, its generation is practically completed, and it can no more be replaced than can the beds of coal removed from a pit. At the same time, as the Silurian rocks lie below the coal-beds, it is not quite easy to reconcile this destructive distillation of coal and shales with the actual circumstances of the case.

Fig. 28.—EXAMPLE OF STALACTITES. THE CURTAIN ("VORHANG"), IN THE CAVERN OF ADELSBERG, CARNIOLA, AUSTRIA.

Fig. 29.—EXAMPLE OF STALAGMITE. MOUNT CALVARY ("CALVARIENBERG"), IN THE MARIA ANNA GROTTO OF THE ADELSBERG CAVERN.

Vegetable mould is a mixture of the remains

of plants with those of the products of the weathering and decomposition of stone. Hence arise the different varieties of soil, its composition and consequent fertility largely depending on the character of the mineral matter which makes up the rock upon which it rests, and of which it is for the most part the worn-down material. The thickness of the soil will also be regulated by the steepness of the ground from which it accumulates in a valley: along the side of a hill it is swept down not only by its own gravity, when it is not tenacious, but by the action of the wind, rain, and melting snow. The character of the soil is, however, altered by its being mixed with the decayed residue of the plants which grew on the surface; this residue, if rank, forms in time humus or vegetable mould. In some instances this is small, while in others, where the land is remarkably rich, as in the Black Earth Region of Russia, it will amount to as much as 12 per cent. Worms bore in and out of the mass in search of organic matter in the soil, and then venting the earthy material on the surface, add no small amount of finely triturated matter to the slowly gathering mould. Darwin, for example, noted in his researches on this subject, that during twenty-nine years worms had deposited six and a half inches of castings on a single field. In centuries, at the same rate, the accumulation must have an important geological significance. In the Tropics, the decay of vegetable humus is of course more speedy than in the colder North. Its decomposition and conversion into soil are expedited by the overflow of rivers, and the mixture of mud and other alluvial deposits amongst it. Hence occurs the richness of "river bottoms," and, it may be added, of drained swamps when the decaying vegetation has not been converted into peat.

Chemically-formed Rocks.—Though these are of less importance than the others, several are of some economic value, and a number of great geological interest. "Stalactites," or the icicle-like bodies which hang from the roofs of limestone caves or similar situations, are among the methods by which the crust of the earth is always reassorting itself. When any spring is charged with mineral matter, which it has dissolved out of the earth, it deposits a portion when the waters rise to the surface, owing to the evaporation and the escape of carbonic acid gas, &c. The limy matter thus deposited is shown by the white incrustation which forms into pendant masses in places like the roofs of caves, or the under surface of the arches of bridges built of limestone, or even when the water percolating through plaster washes out some of the lime. In all limestone deposits the stream and the rain have a tendency to hollow out caves, and form stalactites on the roofs of the caverns, those of the Rock of Gibraltar, of the Island of Antiparos, in the Greek Archipelago, the grotto of the Demoiselles in the Department of the Hérault in France, the grottoes of Arcy, in the Department of Yonne, those of Osselles in Franche-Comté, the Mammoth Cave of Kentucky, the Alabaster Cave of California, the grottoes of Adelsberg, the Rocca grottoes of St. Canzian, in the same region, etc., being excellent examples (Figs. 28, 29). When the droppings from the limestone fall on the floor and rise in a calcareous mound, they are known as "stalagmites," and if the sheet covers the floor it is called a stalagmitic sheet. This form of covering is found at the bottom of many caverns, and has been the means of preserving unsuspected, until the limy mass has broken through, the remains of man and other animals which have lived in these caves, been buried there, or have crept thither to die. Springs charged with carbonate of lime thus produce "calc-tuff" or "calcite," in the form of "calc-spar," and hot springs leave their solid matter in the form of aragonite. Calc-tuff is usually porous, though sometimes it is sufficiently firm to be used in building, being valuable for its lightness.

Travertine is similar to this calc-tuff, though it is usually more compact, hard, and semi-crystalline. Near the famous Falls of Tivoli (Fig. 30), the Anio has formed layer upon layer of travertine from 400 to 500 feet in thickness; and the whole of the Campagna, or plain, east

of Rome, is underlaid with beds of this rock, from which the old Romans hewed the gigantic stones for their splendid buildings. At the Baths of San Filippo it is deposited with such rapidity that in twenty years more than thirty feet have been formed. At the springs in question models are immersed in the water, and the carbonate of lime being deposited on them in a solid form, stone casts are in this manner easily procured.

Gypsum, plaster of Paris, or sulphate of lime, is in its compact form known as alabaster. It occurs as a rock in the form of beds, rarely of any great extent, and in masses or accumulations irregular in form and usually in combination with rock salt, clay, and anhydrite, which is simply gypsum without the water inherent in the latter. It is also found in the form of veins and detached pieces in the masses of other rocks, and is of frequent occurrence in most clays in the shape of isolated crystals or nests.

Selenite, again, is merely transparent gypsum, just as satin-spar is its fibrous form. It is found in clays, and is undoubtedly a deposit from a watery solution.

The formation of this mineral is very rapid, sulphate of lime being produced by the action of sulphuric acid derived from the decomposition of iron pyrites—the "diamonds" of roofing-slates—on carbonate of lime. From the circumstances in which gypsum usually occurs, it is supposed that it is a product of the local conversion of limestone either by the action of gases or by infiltration. It is, however, certain that some deposits of gypsum owe their origin to the evaporation of seawater. The sea contains about sixteen times as much salt as it does gypsum, but the point of saturation for the latter being reached much sooner than that for the former, the gypsum requiring only 37 per cent. of water to be removed, while the salt demands 93 per cent., the gypsum must always be deposited before the salt. It is also possible, as Mr. Jukes-Browne points out, for the deposition of gypsum to take place without the point of saturation for rock salt being reached. Hence, it more frequently occurs as a mineral deposit than salt, though it is not often found in such massive beds.

Silicious tufa, or sinter—the latter being a firm the former a porous mass—is a deposit from hot springs which contain much silica or flinty matter in solution. The hot-springs of Iceland, and the geysers of that island and of New Zealand, and of the Yellowstone country in America, are excellent examples of these, as we shall see when we come to describe the various geological agents engaged in making and remodelling the earth. Immense deposits of silica have in this way been laid down, the silica being, most probably, as in Iceland, dissolved out of the lavas below, and is held in solution as a hydrate by the alkaline carbonates and sulphates. Bunsen observed that no silica is precipitated on the cooling of the water. It is only after its evaporation that the silica is deposited in a thin film on the moistened sides of the vessel. In the Azores, also, there are several such springs, though in no case are they so marked as in the regions mentioned.

Bog iron, or limonite, is a "rock" only in the geological sense—that is, it forms part of the materials entering into the composition of the earth's crust. When springs, or other water, charged with iron are allowed to settle, they discharge a brownish or red scum of peroxide of iron on their banks or at the bottom of ponds and marshes. In time these form masses of iron ore, which are known as "bog" or "marsh ore" (p. 63), and when sand or gravel gets mixed up with it, this variety of ironstone is sometimes called "sand iron." Tangled masses of mineral have sometimes been known to have been abstracted from the solution by a diatom —a microscopic plant covered with a delicately sculptured flinty case—called *Gallionella ferruginea*. In Sweden these masses of bog iron are found at the bottom of the great lakes. When the lakes are ice-bound the ore-gatherers go out "prospecting" in search of this "malm." They first of all make small holes in the ice, through which they pass a pole long enough to reach the bottom, which is generally at no great depth, as the ores are

collected among the shallows and reed-beds. By long practice the collector knows whether or not there is ore at the bottom, and when he settles this point he stakes off his "claim" with pegs driven into ice. Then making an opening sufficiently large he passes through it a sieve fixed to the end of a pole, which rests on the ground. Into this riddle he rakes the ore, and empties it on the ice. In 1860 about 22,000 tons of ore were collected in this fashion, and the beds, which vary in thickness from eight to thirty inches, after being exhausted are said to be renewed in about twenty-five years. Bog-iron ore is also found at places now covered by the sea. For example, Nordenskjöld tells us, the shells of crabs and pebbles dredged up in the Kara Sea are often surrounded by incrustations of bog iron. This also occurs over an extensive area north-east of Port Dickson, near the mouth of the Yenisei, a Siberian river, in such quantity that it might be used for the manufacture of iron were this part of the world less inaccessible. This fact is not surprising, since the shores of the Arctic Sea in this region bear every sign of having been alternately elevated and depressed. The general theory held regarding these lacustrine ores is that they are the ferruginous deposits washed down into the lakes by rivers from the surrounding country. But Herr Sjögreen attributes them, as did Ehrenberg, to minute organisms extracting the iron from the water in which it is held in solution. The presence of phosphoric acid in bog iron ore, which renders it unfavourable for smelting, is due to the decay of these organisms in it when forming.

Sulphur is found in great beds in Iceland, Sicily, and in the vicinity of volcanoes generally, and in the environs of Rimini there are beds contained in a calcareous marl, varying in thickness from four to thirty-one feet. It is due to the oxidation of the sulphuretted hydrogen, which is discharged in great quantities along with the steam issuing from the vents, known as "solfataras," found so abundantly in nearly every volcanic district. Or it may arise owing to the decomposition of sulphates and other minerals previously existing in the earth's crust. Perhaps, also, the presence of sulphur crystals shows that it might have been formed in water through the decomposition of sulphuretted hydrogen, as sulphur melts at 238·1° Fahr. In Sicily, Spain, and other localities, it has been formed by the decomposition of gypsum (sulphate of lime, or calcium-sulphate, as the latter-day chemist would say), and, strangely enough, the sulphur thus made by weathering is in certain localities becoming converted into sulphuric acid, or oil of vitriol, which, when limestone is present, re-forms gypsum, or "borscale," which in Sicily is looked upon as a sign that sulphur is underneath.

All mineral veins may be regarded as chemically-formed rocks, though, as they are for the most part veins running through other beds, we may more conveniently consider their origin when we come to discuss the nature of these important tenants of rocks, both stratified and unstratified. Recent researches have, however, gone far to render possible the assertion of Nordenskjöld and others, that a large portion of the earth's constituents may be of cosmic origin—that, in other words, in the course of ages the distant stars and other heavenly bodies may have contributed of their substance to thicken the crust of our world. For example, at various times, and in various places, there has been collected from the snow a black powder containing metallic iron, and, in some instances, cobalt and nickel, while on the "inland" ice which covers Greenland a peculiar mineral powder, named kryokonite, mixed with grains of metallic iron, has been detected. This dust consists of small, angular, double-refracting crystal fragments, without any mixture of particles of glass, and is, therefore, very different from the glass-dust that is commonly ejected from volcanoes. From these and similar data Nordenskjöld ventures on the assertion that not improbably, if this dust falls in an equal amount all over the globe—and though the snow enables it to be detected more easily than on earth, there is no reason for supposing that it does not—something like half a million tons drop from the celestial spaces in the course of a year. The

Fig. 30.—THE FALLS OF THE ANIO AT TIVOLI, NEAR ROME.

shooting stars must discharge an immense quantity of those luminous particles. For hours at a time we see them falling; and when we remember that this has been going on during unnumbered geological ages it is not impossible to regard it as an important factor in the history of our planet. In brief, it may be found "that a considerable quantity of the constituents of our sedimentary strata, especially of those that have been deposited in the open sea far from land, are of cosmic origin, and will throw an unexpected light on the origin of the fire-hearths of the volcanoes, and afford a simple explanation of the remarkable resemblance which unmistakably exists between plutonic rocks and meteoric stones, namely, by showing that the principal material of the plutonic and volcanic rocks is of cosmic origin, and that the phenomena of heat which occur in these layers depend on chemical changes to which the cosmic sediment, after being covered by thick terrestrial formations, is subjected." * Without quite homologating this idea, it is certain, as we shall learn more fully when this section of our theme comes to be discussed, that meteoric, or native, iron is—and has from the remotest ages been—falling on the earth's surface from the immeasurably distant regions outside of our atmosphere.

But perhaps the most extensive and at the same time best known chemical rocks are those made of *rock salt*. They form extensive masses, "lenticular" (lentil-shaped), usually in clayey deposits, and are always accompanied by gypsum. Salt also forms an ingredient of some clays, and in small quantities is found in limestone. In England the most extensive deposits are in the New Red Sandstone of Cheshire, underlying the bed of the Weaver. There are also deposits in Worcestershire, Staffordshire, and several of the northern counties, and in County Down, though none of them supply more than a fraction of the amount derived from the Cheshire beds, which spread over an area 30 miles in length, and from 10 to 15 in breadth, some of the strata being from 90 to 170 feet in thickness. The Marston Mine is excavated to a depth of 16 feet over an area of about 40 acres, the roof being supported on huge pillars of the native rock left at stated intervals. In this neighbourhood, owing to the dissolution of the salt by the infiltrated rain-water, the ground is sinking in many places, to the great damage of the superincumbent buildings. In some localities the brine rises to the surface, in others it is pumped out, but it forms almost as rapidly as it can be evaporated for the sake of the salt held in solution. But for the most part the salt of commerce is derived from the iron-stained solid blocks, which are subjected to various refining processes before the material appears on the table. In the province of Galicia, in Austria, there are masses of rock salt computed to cover over 10,000 square miles. Already the workings are said to extend for a distance of 30 miles, and in places the salt has been hewn away to form large halls 100 feet in height. In Asia, America, and Africa, there are also numerous deposits of salt, sometimes pure, at other times mixed up with clay and other materials which have originally been deposited with it.

These accumulations do not belong to any special geological period, and, indeed, from the way in which they seem to have been formed, no necessity exists for their connection with particular epochs. Here and there, as at Vienna, springs deposit a fine powder, which consists of gypsum and muriate of lime, and in Russia several lakes overflow their banks and deposit a saline crust. In Egypt, carbonate of soda has in this manner been deposited in great quantities, and the extensive turf moors of Franzenbad, near Eger, in Bohemia, are partly covered with a coat of Glauber's salts (sulphate of soda) and sulphate of iron, derived from the springs which form the principal attraction of that watering-place. In that tract of the Pampas of South America, known as Las Salinas, forty leagues are strewn with beds of nitrate of soda mixed with gypsum, common salt, Glauber's salts, and remains of recent—that is, non-fossil—shells. Some salts

* Nordenskjöld: "Voyage of the *Vega*" (1881), Vol. I., p. 331.

form efflorescences in rocks. As examples of these, the nitrate of soda (saltpetre) found in the limestone caverns of Brazil and Ceylon might be named, while the "alkali" of the Central North American plains is derived from the soil in which it is contained. The deposits of crude nitre in the Atacama deserts, and the borax deposits in California and other parts of the world, are specimens of crystalline matter which have been left on the surface after the lake or other water in which it was originally dissolved had evaporated.

In a similar manner, no doubt, the deposits of salt have been formed. To take one example out of many which could be cited: before the Suez Canal was dug, the surface of the Bitter Lakes was much below the level of the Red Sea, and the evaporation of these waters had produced a bank of salt 1,600 acres in extent, composed of layers two to ten inches in thickness. It would appear that these "lagoons"* had been inundated from time to time by the waters of the Red Sea, while, in the interval between these incursions the evaporation and concentration were sufficient to precipitate a layer of salt, and so in time the large deposit above mentioned was accumulated.† In the "limans" of Bessarabia, on the Black Sea, which dry up in the summer, salt beds are growing before the eyes of any one who chooses to watch the process. Again, Mr. Darwin, in speaking of the salt deposits of South America, notes that it is remarkable that all the circumstances connected with the salt lakes in Siberia and Patagonia are similar. Siberia, like Patagonia, appears to have been comparatively recently elevated above the waters of the sea. In both countries, the salt lakes occupy shallow depressions on the plains; in both, the mud on the borders is black and fetid; beneath the crust of common salt, deposits of sulphate of soda or of magnesia occur, imperfectly crystallised; and in both the muddy sand is mixed with lentils of gypsum. As these circumstances, apparently so trifling, occur in two distinct continents, we may feel sure that they are necessary results of common causes.‡ The rock salt of England lies above the beds of magnesian conglomerate in the New Red Sandstone series of the great marshy plains of Lancashire, Cheshire, and Worcestershire. It is found at different depths, in beds ranging from a few feet to about 120 feet in thickness. No fossils occur in the salt, and it is usually of a reddish colour, owing to the presence of particles of iron rust. Sir Andrew Ramsay considers that there is no doubt that these salt beds were due to precipitation from supersaturated salt lakes, by the action of solar heat on the water of salt lakes which had no outflow, like the Great Salt Lake of Utah for example, or the salt lakes of Central Asia and of the Sahara. That salt forms an ingredient of certain rocks may be readily understood when it is taken for granted—an assumption which will presently be proved—that all sedimentary beds have been laid down under the action of water. Indeed, at the present moment extensive regions, especially those at the mouths of rivers, are, after being deserted by the water, rapidly passing through the stages of salt marsh and fen-land. Many such tracts exist in Holland, in the ancient Gulf of Poitou, in the filled-up estuary of Flanders, and so forth, and when the Zuyder Zee—which, again, occupies the site of old lakes—will be shut off from the German Ocean and drained, its soil must necessarily be heavily impregnated with saline matter.

* This familiar word is from the Italian "laguna," and means a shallow salt-water lake, or sheet of water, almost or entirely cut off from the sea by an intervening strip of beach. It is also applied to the water enclosed by circular coral reefs.

† Jukes-Browne: "Handbook of Physical Geology" (1884), p. 210.

‡ "Naturalist's Voyage" (1860), p. 67; Bremner, "Science for All," Vol. II., p. 279.

CHAPTER III.

The Stratified Rocks: their Upheaval and Dislocation.

Stratified Rocks, how formed—Upheaval and Irregularity of Beds—Beds rarely horizontal—Beds not formed in the Deep Sea—Chalk—Mode in which Beds are Tilted—Syncline and Anticline—Curved and Folded Beds—Dip and Strike—Outcrop—Escarpments—Outliers—Conformability and Unconformability—Overlap—False Bedding—Ripple Marks—Dislocation of Beds—Faults—Joints.

It is evident from what we have learned regarding the character of the strata or beds, of the stratified rocks, that all have, more or less, been deposited under the action of water. They are all "clastic," or fragmentary, if we except the chemically-formed beds, and, to a certain extent, those which, like coal, are formed by the decay of vegetation, or, like chalk, are composed of the shells of foraminifera. That is to say, they have been derived by the wearing down of pre-existing rocks. But even the partial exceptions which we have mentioned come more or less into this category also, since, mingled with them, are beds of detrital matter in some form or other. These derivative rocks may be composed of gravel, sand, or mud, brought down by rivers, and deposited in the sea or lake into which the river flows. Or the winds may have swept the sand into great dunes, such as we see on the shore or in the deserts of Africa and Asia; or, as we find in volcanic tuffs, they have come from the materials vomited forth by volcanoes; or, as in the case of the glacial clays, have been formed out of the *débris* ground off the underlying rocks by the glaciers which moved over them. In very exceptional cases it happens that though such materials are in beds, water has not played its assorting part in re-arranging the substances. This, however, almost invariably holds true of very recent deposits, since there is scarcely a foot of the ancient earth which has not been at one time or other under the sea. It is, therefore, unnecessary for the purposes of the physical geographer to take these very specially into consideration. When we speak of volcanic and ice action, all that is necessary will be said of their influence geologically. Meantime, what has been presaged regarding rocks which are *igneous*, plutonic, or unstratified, and those which are *neptunian*, aqueous, or stratified, may be considered as holding good throughout the earth's crust.

Taking a simple example of how strata might be laid down by one of the means specified, let us suppose a great river pouring into the sea. It would deposit first, let us say, a bed of mud, derived from the wearing away of its banks, then a bed of gravel might be laid down, or sand might follow this, and so on; or all these might be mixed together, the strata on the bottom of the sea, or on that of the lake into which the river flowed, being entirely dependent on the character of the previously-formed strata with which it came in contact during its course. By the pressure of the superincumbent beds, or by the infiltration of lime or other connecting material, or the action of heat, these deposits would in time get consolidated. They would also, necessarily, contain the remains of plants and animals which had been embedded in the mud or sand, though the degree of preservation of these "fossils" will of course depend, first, on their hardness, and, secondly, on the degree with which the soft particles of their structure are replaced in the process of fossilisation by the harder ones of the material in which they are embedded. Thus, most shells will remain intact, while soft-bodied animals will, so far as their fleshy particles are concerned, entirely disappear.

As we have seen that there is every probability, from what the late deep-sea dredgings have brought to light, that few, if any, of the beds of rock were originally deposited in the greatest depths of the sea, it

necessarily follows, from the great thickness of the sedimentary strata, that they must have undergone many changes since they first began to be laid down. The fossiliferous strata of Europe have been calculated to be some fourteen miles in thickness, and even at one single place it is not uncommon to see several hundred feet of beds exposed, without taking into account those which are partially concealed from view. Most probably, therefore, as the shores of many continents are at the present day oscillating, these vast beds of strata have been gradually deposited while the sea-floor on which they are laid has been sinking. That they have taken very long periods to be deposited we know, since the fossils contained in the lower ones are often very different from those preserved in the upper ones, the lapse of time serving to admit of the missing species dying out of existence. Hence the oldest rocks in the earth's crust contain an altogether different collection of animal and vegetable remains from those which are of later date. It is also equally clear that, whether laid down in deep or in shallow water, the beds have been elevated since their formation. This is proved by the fact that strata with marine shells are found on the tops of mountains which bear no trace of ever having been the floor of the deep sea. The older geologists explained this phenomenon by saying that the sea had retreated; but the sea never retreats locally, while we shall learn by-and-by that there are parts of the world where, in modern times, the earth is sinking, and others in the close neighbourhood where it is rising.

Upheaval and Irregularity of Beds.

What is more, the beds after having been laid down and consolidated must have undergone violent disturbances. If they had not, they would be at this moment perfectly level, since, of course, they could not—except in very exceptional cases—have been deposited in a sloping position, and without any breaks or dislocations. In Sicily there are beds some 2,000 feet in thickness which might be described as of this nature. They are of comparatively recent date in geological history, but south of Lake Wetter, in Sweden, there are very ancient rocks of Silurian and Cambrian age, which are as horizontal as if laid down yesterday, though, doubtless, ages must have elapsed since they were first slowly raised from the bottom of the sea. Again, Table Mountain, in the Cape of Good Hope, though 3,500 feet in height, and composed of old strata, is, as its name expresses, almost if not quite flat.

This, however, is not often the case. On the contrary, as a glance at any railway cutting or sea-cliff will show, the strata are usually sloping, in some instances absolutely on end (Fig. 31), now and then curved, and occasionly perfectly reversed. From the presence of certain fossils in the beds, we ascertain that these have in places an alternation of marine and fresh-water beds, and even of rocks, some of which must have been formed in shallow and some in deeper water. Thus, if it is a cause for amazement to see marine shells far above the sea-level, it is still more astonishing to sink in a few feet through beds where the alternation of the strata shows that an estuarine deposit was succeeded by those formed in the true sea, and the sea by a lake, and the deep water again by shallows. For example, in sinking through the stiff London clay which underlies so much of the Thames valley, we come first on a clay of marine origin, then at a depth of several hundred feet on shallow water and fluviatile sand; finally, beneath this comes the white chalk, which must have been formed in a much deeper sea. Indeed, the chalk is about the only rock which there is any evidence of having been formed

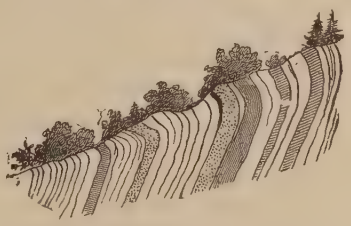


Fig. 31.—ALMOST VERTICAL STRATA.

The beds show "over-lapping," thus proving that superposition is not a true test of age; in this case the beds which on the surface seem uppermost, being in reality the undermost.

in mid-ocean. In taking soundings in the Atlantic, the lead brings up a limy ooze which bears a strong resemblance to the ancient chalk. But Sir Wyville Thomson, when he formulated the dictum that we "were living in the Cretaceous period," uttered a paradox, rather than a truism. The Atlantic ooze is in many respects different from the ancient chalk. The one is made up almost entirely—so far as the limy material in it is concerned—of the *débris* of the shells of foraminifera, but, according to Mr. Sorby, many of the minute particles which make up the mass of the chalk have been derived from the decomposition of various other shells. Foraminifera form a very important constituent, yet other larger calcareous organisms "have probably yielded the greater part of the rock. It is, therefore, very far from being identical with the Globerigerina ooze * of our modern deep oceans, though there is an interesting connection between them." There is more silica in the ooze than there is in the chalk, while the amount of carbonate of lime in the latter is greater than in the former, though the deeper the samples are taken the nearer it approximates in composition to the chalk. We may, therefore, venture to conclude that the beds of chalk were deposited at a considerable distance from land, and probably in comparatively deep water.

These elevated rocks, containing sea-shells and other evidence of the materials out of which they are composed, having, therefore, been laid down at sea-level, must have been raised to the position they now occupy. Still more clearly are we led to the conclusion that since the stratified rocks were first formed in the manner indicated, violent forces have been at work in the earth's crust, when we see the rocks not only raised high above the sea-level, and twisted and tilted in every degree, but dislocated in various ways. We follow, for example, a bed for a certain distance, then suddenly it ends abruptly, the remainder having slipped above or below the level of the other portion. In other words, it has been broken in such a manner that it and the strata of which it forms a part, have been, to use a familiar term, thrown out of joint.

* The *Biloculina* mud of the Norwegian explorers of the North Sea.

It is therefore necessary, before considering the modern forces now at work, which might in the past have produced these and other geological changes, to examine the principal ways in which rocks lie in the earth's crust.

Syncline and Anticline.—We have already intimated that it is rare to find strata perfectly horizontal. They slope at every angle from the slightest tilting to a position in which the beds stand perfectly upright. Such vertical strata were found, among other places (Fig. 31), in the rocks on which Powis Castle is

Fig. 32.—DECEPTIVE ANTICLINAL BEDS.

In reality beds were originally overturned into the shape of an arch, after which some of the beds have had their tops removed.

built, and in the Grampians, where beds of conglomerate and sand alternate; but as the egg-shaped pebbles of which the conglomerate is composed stand on end, it is clear, other

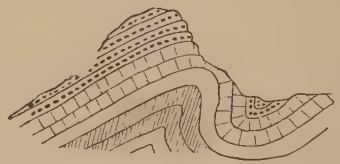


Fig. 33.—FOLDED BEDS, SOME OF WHICH HAVE BEEN REMOVED.

reasons apart, that as eggs do not naturally stand on their ends, the pebbles must have originally been deposited with their largest axis parallel to the plain of bedding, and been afterwards raised into the position they now occupy, by the strata of which they form a part having been tilted vertically. The chalk and other beds at Alum and Whitecliff Bays, in the Isle of Wight, are also almost vertical. Sometimes the strata by pressure have assumed a more or less curved shape, and in not a few instances they are actually doubled on each other, not unfrequently in several bends; which circumstance, the upturned edges of the different beds having been examined

without our obtaining any clue to the cause, is apt to lead to a mistake, the duplications of a single bed appearing as if there were several beds. Indeed, a bed will sometimes double up and down in this way for miles, so that the strata appear like a series of the

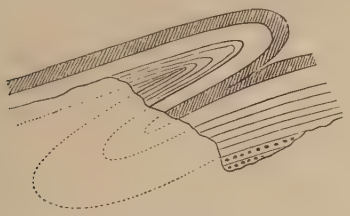


Fig. 34.—INVERTED STRATA, SOME OF THE FOLDS WORN AWAY.

letter **W** placed in rows. When the strata incline towards each other like the two legs of a **V**, they are described as "synclinal;" if the contrary is the case, as in the inverted **Λ**, the beds are described as "anticlinal." Or this relation of bed to bed may be illustrated by means of a book: let it lie flat on the table, then the leaves will represent strata in a perfectly horizontal position; place it on end, then the beds are vertical, as in the rocks described (p. 73 and Fig. 41); open the book a little in the middle, and then the leaves on each side of the opening will represent synclinal strata; turn it over, so that the book will lie with its edges on the table, then the boards sloping away from back are examples of anticlinal strata; finally, if several books all partially open are arranged in a line, but some with their backs on the table, and some with their edges, they will in a rough fashion show the mode in which strata are often found in the earthy crust.

Curved and Folded Beds.—In examining the crust of the earth more critically, we find that the arrangements are not always so simple as this. The strata have not only been doubled, but they have been reversed in great arches, the tops of which have been cut off by the weather, or other agencies acting on the surface. The diagrams (Figs. 32, 33, 34, 35) show some of these results, where the same bed appears twice, and in a position which, did we not detect the arrangement described, might lead us to believe that the two

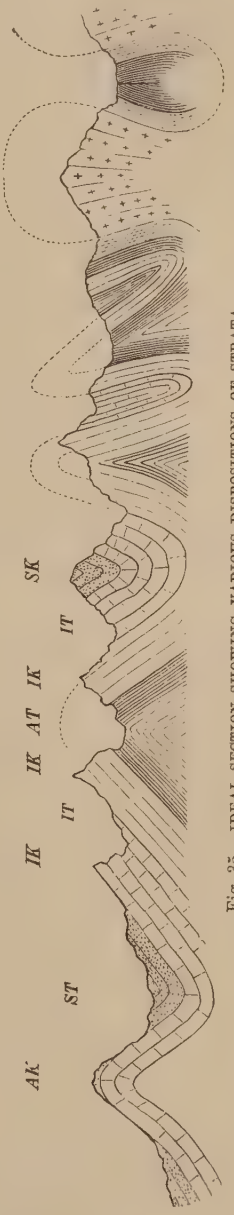


Fig. 35.—IDEAL SECTION SHOWING VARIOUS DISPOSITIONS OF STRATA.

AK.—Anticlinal crest or saddle. *AT.*—Anticlinal valley formed by the crest of the anticline being removed. *IK.*—Isoclinal crest. *IT.*—Isoclinal valley. *SK.*—Synclinal crest. *ST.*—Synclinal valley, or trough. The strata to the right show isoclinal folding, and that peculiar mode of plication, which, as in Mont Blanc, is known as the fan-tail arrangement (*Structure en éventail*, or, as the Germans say, *Fächer-falten*).

were different beds and of different ages. They are, however, only "isoclinal," or folded

strata sloping all in the same direction. These sections also explain some other facts regarding the disposition of strata.

It may be added that in some strata the plication becomes so extreme that the beds are crumpled, corrugated, or puckered to such an extent that it is difficult or impossible to follow the course of the folds. Contortion of the kind we have described is mainly found in the newer rocks, while the oldest ones are most dislocated.

Dip and Strike.—This leads us to explain what is meant by "dip" and "strike." Dip is the inclination of the strata from a horizontal position, and the steepness at which they slope from the horizontal is described as so many degrees to the east and west, or whatever may be the direction. There being 360° in a circle, a vertical set of rocks would stand at an angle of 90°, while those which slope halfway between the horizontal and the vertical would be marked as possessing a dip of 45°, and so on, as their inclination was greater or

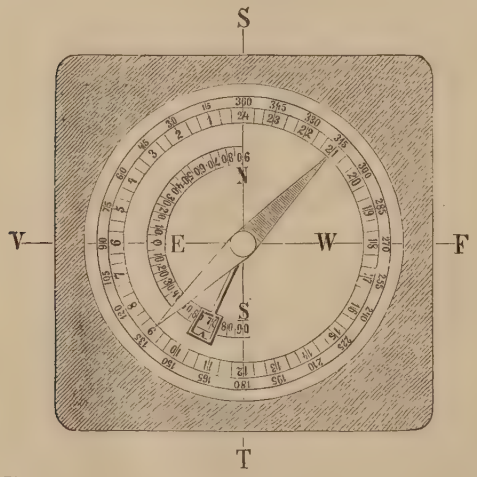


Fig. 36.—THE GEOLOGIST'S COMPASS WITH CLINOMETER ATTACHED.

ST.—Direction of Strike. VF.—Direction of Dip.

less. This is measured by an instrument called the clinometer, which is usually a little plummet attached to the compass used for geological surveying (Fig. 36). Or it can be noted with sufficient accuracy for ordinary purposes by standing opposite to a cliff where the true dip is exhibited, and then, to use the words of Lyell, "holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular, and of the other in a horizontal position. It is thus easy to discover whether the lines of the enclosed beds bisect the angle of 90° formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. You have only to change hands to get the line of dip on the upper side of the horizontal hand."

On the other hand, the strike is the prolongation of the strata at right angles to the dip; in other words, it is the *direction* of the strata. It must, therefore, always be in an opposite direction (Fig. 37). Thus, if the beds dip to

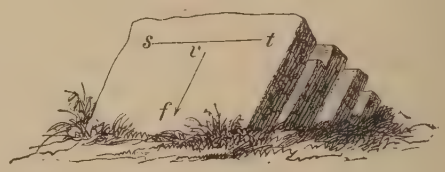


Fig. 37.—DIP AND STRIKE.

st.—The Strike. *vf.*—The Dip.

the east, their strike must necessarily be north and south. Thus having ascertained the dip, we can easily enough fix the direction of the strike. But the converse of this does not hold good, for strata dip in different directions; hence there are two lines of dip to every line of strike, so that strata having a strike running from north to south, may dip either to east or west.

These facts Sir Charles Lyell has illustrated by comparing dip and strike to a row of houses running east and west, "the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north and on the other to the south." A still easier mode of illustrating these elementary facts may be found by manipulating a book. Place a book on the table with the edges of the leaves downward, and the back of the book upwards. If one side of the cover is moved a short distance, the cover so moved will represent the line of dip, while the back

of the volume will exemplify the line of strike. If the cover of the book is extended only in a slight degree the dip will be proportionately steep; if the cover be opened farther, so that the book lies nearly flat on the table, the dip will be proportionately less.* It will sometimes happen that the strata having been elevated into a dome-shaped protuberance, the summit of which has been carried away, the ground-plan exhibits the edges of the strata forming "a succession of circles or ellipses round a common centre." These circles are, of course, the line of strike, and "the dip, being always at right angles, is inclined in the course of the circuit to every point of the compass," constituting a "quâ-quâ-versal dip," that is, a dip turning any way. Such beds have been termed "periclinals," and a great many technical expressions are used by geological surveyors to express the different ways in which they show themselves, though for our purpose it would be superfluous to trouble the reader with this vocabulary.

It is, perhaps, unnecessary to point out the importance which the dip and strike have in mining operations, for on the steepness of the angle at which the beds incline to the horizon will depend the ease or difficulty of working them. If they suddenly dip down at a sharp angle, the "prospector" may have to sink a very deep shaft to reach them, or possibly find it difficult to get at them at all. On the other hand, if they incline very little from the horizontal, he may, mole-like, burrow along their continuation without requiring to sink shaft after shaft, each one deeper than its predecessor, until, in time, the coal, let us say, escapes him altogether, or, still worse, until he knows in what direction the beds are dipping. It often happens, of course, that the edges of inclined or bent strata appear on the surface, and when they have been smoothed by the wearing-away action of rivers, rain, ice, or other agency, we can easily observe the succession of beds, though, for the reasons already mentioned, errors may arise as to the number of separate strata and the order in which they originally succeeded each other. Indeed, it is not unknown in the history of stratification to find a series of beds absolutely inverted (Fig. 34), that is to say, they have been so disturbed that the oldest—namely, the lowest beds—have got turned over, and being uppermost might be supposed to be the newest. This may arise from a variety of causes, one of the most frequent being that the beds are first bent into folds, and these, by a second tilting, are thrown still farther out of their original position.

Outcrop, escarpments, outliers.—The appearance of the edges of strata at the surface is known as their "outcrop" or, as the miners say, the "basset," while the line along which the upper surface of a bed of rock rises out of the ground is styled its "line of outcrop."

When strata terminate abruptly, as in cliffs, they form "escarpments," which, if very steep, are known as "mural" or wall-like escarpments.

When beds of rock lie isolated from the principal masses of the same strata, of which they have evidently at one time formed a part, they are called "outliers." In such cases there are almost certain to be evidences of some agency which has resulted in the continuity of the beds having been broken, either by disrupting them, or more frequently by the removal of those which are now represented by the gap.

Conformability and unconformability.—When beds have not been so violently disturbed as to become reversed, we have a right to conclude that the undermost ones are the oldest, and the topmost the newest, geologically speaking (Fig. 38). When the one on the top lies prone to the one under it, like

Fig. 38.—IDEAL SECTION SHOWING HOW THE EYE MAY BE DECEIVED BY STRIKE AND DIP.

The strata *a* dip alongside the mountain in one direction at an angle of about 45° from the horizon. Those marked *b*, on the other side of the mountain, seem to dip at the same angle and in the same direction. In reality this is not the case. Owing to the weathering being the same on both sides it is the strike which is exposed at *b*.

* Richardson's "Geology and Palæontology," edited by Dr. Thomas Wright, p. 147.

two books lying the one on the other, the beds are called "conformable" (Fig. 39). But we find beds lying, say on the upturned edges of others, like books laid on the upper edges of upright ones, then these strata are said to be "unconformable" (Figs. 40, 41). Such appearances are by no means uncommon. They are exhibited in many places, among others at Siccar Point, near St. Abb's Head, in Berwickshire, where the Old Red Sandstone lies in a sloping position on the edges of the vertical and arched Silurian schists;* or at Frome, in Somersetshire, where Dr. Geikie figures the inferior Oolite lying horizontally on the inclined Carboniferous strata. Again, at Cullen, in Banffshire, the same distinguished geologist has sketched a double unconformability—viz., the Old Red Sandstone lying on "quartzite," and gravels of a much more recent date resting, in their turn, unconformably on it. Lastly, not to multiply examples of a common arrangement of strata, a good instance of unconformability is figured by Jukes from a section near Thomastown, Kilkenny; it may be added that the newer and older strata composing the mountains of the Vienna Forest are unconformable with each other. Unconformability is, of course, a proof of a break in the geological succession. In other

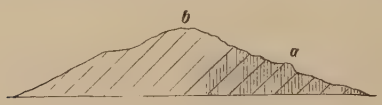


Fig. 39.—CONFORMABLE BEDS.

The strata are not necessarily of an approximate age. But as *b* lies exactly on *a* below it, it is clear that *a* was not tilted out of the horizontal before the material of which *b* is made up was laid down over it. Both sets of beds must have been upheaved at the same time.

words, as the same convulsion could not have tilted one set of beds into a vertical position and permitted those lying on them to remain more or less horizontal, the under ones must have been laid down and tilted up before the uppermost ones were deposited on their upturned edges or other surface lying at a different angle. Hence there is every ground for concluding that between the two events a long period—long, even as geological time goes—must have elapsed. This is still more evident when the under series of beds exhibit marks of having been elevated subsequent to their subjection to the subterranean force by which they were thrown off the horizontal, of their having been worn by aërial agents when a dry-land surface, and then, of course, of having been buried under the sea to admit of the deposition of the beds which lie unconformable with them. It even happens that the

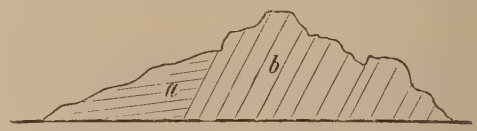


Fig. 40.—UNCONFORMABLE STRATA.

Those at *b* have been tilted up before those marked *a* have been deposited either in contiguity to them (though at a very different dip) or, perhaps, on their upturned edges, from which they have subsequently been removed by weathering.

underlying strata are disjointed and dislocated in the fashion we shall presently see without the upper ones being in any way acted on in a like manner. In this case the lapse between

Fig. 41.—UNCONFORMABLE STRATA.

The beds *a* have been deposited after the beds *b* and *c* have been tilted up.

the two sets of beds must presumably have been greater than when the difference of angle is less, and can only be detected when a large extent of country is surveyed. In strata, the greater unconformability and the greater discordance between the two beds or series of beds the greater the likelihood of the one being much older than the other, or *vice versâ*.

Overlap is a term employed to express the fact that one bed extends so much farther than that immediately below as to conceal its edge. This disposition of strata may have been occasioned either by the river which brought down the material out of which they are composed, having a greater amount of volume at a later than an earlier period, so that the sediment was deposited over a wider area than before; or,

* These beds are figured in Lyell's "Elements," p. 71 (Fig. 78).

it has been suggested, overlapping may be due to the fact that the sea bottom has been raised up, and again depressed without disturbing the horizontal position of the strata. In this case the newer strata may rest for the most part conformably on the older, but, extending farther, pass over their edges. The overlapping beds then stretch farther and farther out as the lower ones gradually subside, generally with a slope. It does not therefore follow that overlapping beds need be unconformable. Indeed, the term is strictly applied to conformable beds. But as not unfrequently there has been a slight derangement or wearing away of the underlying beds before the newer ones were laid down, Sir Charles Lyell only expresses a conclusion which is irresistible when he states that every intermediate step between unconformable and overlapping beds may and does occur. Overlapping may also occur when strata are partially curved (Fig. 31), though this artificial form of overlapping is easily detected. It is also self-evident that if the possibility of overlap is not taken into account, a prospector boring, let us say, for coal, may entirely miscalculate the thickness of the upper set of beds. Again, as Mr. Jukes-Browne has pointed out with great clearness, the vast sums of money which have been thrown away in search for coal in the central districts of England might have been saved had the miners been aware of the manner in which conformability and unconformability may interfere with their calculations. Here the Coal Measures rest unconformably upon the ancient rocks called Silurian, and are themselves unconformably overlaid by newer deposits of Sandstone and Conglomerate. In Antrim, again, where the Trias or New Red Sandstone rests on the Carboniferous rocks, it has been thought that if once the Sandstones are pierced, the Coal Measures will be reached. But if the one lies unconformably on the other, it may happen that while in one locality the Trias rests upon the Coal Measures, in other places "it may lie upon any of the beds which come out from beneath the Coal Measures; and from the structure of the district it appears that the chances are something like twenty to one against the Coal Measures being found under any particular spot of the Trias." *

False Bedding occurs when the strata are not exactly superimposed in beds, each resting evenly on that below. They may be diagonal, or in various other ways different from what ordinarily prevails, this appearance being, no doubt, due to eddies in the currents by which the beds were originally laid down, or in the sea, on the bottom of which they were deposited, the same divergence from the rule being often noticed in modern sandbanks or the extensive accumulations of mud which form at the mouths of modern rivers.

Another irregularity of bedding is produced by what the miners know as "rolls," "swells," or "horses' backs," and "wants." The two are exactly the opposite of each other. A roll, swell, or horse's back consists in a portion of the lower bed being protruded out of its due place into the one which lies over it, though it is in other respects quite regular; while a want is where a place has been scooped out of an underlying stratum, and filled with the material out of which the one lying over it is composed.

Ripple Marks, etc., on rock beds are a series of wavy ridglets, such as are seen on the beach just after the tide has retired, and may reasonably enough be attributed to the same cause operating on the ancient sea-shores. They are confined to certain sandstones and sandy shales into which mud enters largely. If a beach on which such ripple marks had formed was permitted to bake or harden, it would not be difficult for another layer of mud or sand to be deposited over it without effacing the first impressions. In like manner, even the marks made by passing showers have been preserved, and, as we shall see by-and-by, the trail of sea snails, the burrows of worms, and the footprints of birds and other animals, have in this manner left their records on the rocks.

Dislocation of Beds.

It is extremely rare to find any of the rock beds in the earth's crust which have not been more or less disturbed since first they were

* Jukes-Browne: "Handbook of Physical Geology," p. 389.

laid down, and, in all likelihood, every age of the earth has witnessed more or less disturbance either by volcanic forces having been at work, or by earthquakes having riven the strata which compose its crust. The form of disturbance which will, however, form the theme of the present remarks is that exhibited in "faults."

Faults.—A bed, or series of beds, are often found dislocated. The continuity of the strata has been broken by one portion of them having been shifted up or down, so that in following out a seam of coal we come suddenly to a point where it terminates, and one thoroughly understand the geology of the district, to imagine that the shifted fragments of the dislocated seam are in reality several beds, and thus spend much time and money only in the end to reap disappointment. Sometimes, especially in soft rocks, the line of fault is tolerably clean cut, but in hard beds, the edges of the shifted strata are rough and broken, with pieces of the disrupted rocks jammed into the crack. Often the fault is undulating; occasionally it is straight, and at various angles from perpendicular to forty-five degrees or less, and though it may consist simply of displacement of strata, as in Figs.

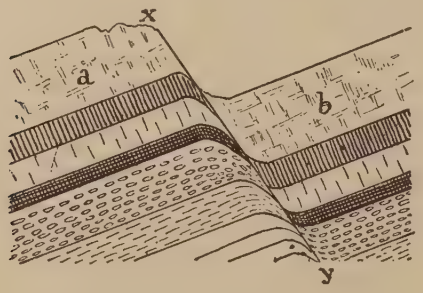


Fig. 42.—DOWN-THROW.

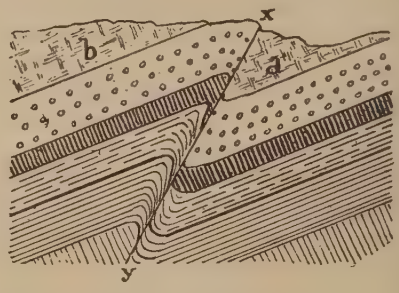


Fig. 43.—UP-THROW.

x, *y*, line of fault. *a*, *b*, the displaced beds. In the one case the fault is reversed; in the other it is regular.

of sandstone takes its place; or in tunnelling along a bed of limestone we come as unexpectedly on one of shale, without either bed exhibiting any symptoms of thinning out or coming to a natural termination. We then know that there has been, as the miners say, a "hitch," or a "down-throw," or "up-throw," as the case may be, and to search for the lost stratum we must bore down, or probe, the beds at another level (Figs. 42, 43).

Thus a fault is not really without its advantage to the miner. It often enables him to reach beds which would otherwise be less accessible. Moreover, when the crack is filled up with foreign matter it serves as a kind of wall, which checks the progress of a fire along an entire coal bed, and acts as an embankment which prevents the too rapid flooding of a mine. But where there are several faults (Fig. 44), the prospector is apt, unless he 42, 43, it is easy to understand how it might be complicated by the softness or hardness of the broken beds, by various local circumstances, or by the strain from the subterranean motion which caused the original dislocation reacting repeatedly on the shifted beds. Hence faults form an important branch of geological study. The throw or amount of displacement produced by a fault is measured by the vertical distance between the two ends of the broken bed. This displacement may vary from a few feet to many hundreds, or even thousands, so that in juxtaposition may lie the broken ends of beds of widely different ages. The inclination of the fault is known as its "hade," or underlie, and this inclination has a certain relation to the direction of its "throw." For example, the fault generally, as in Fig. 42, "hades" under the beds thrown down. But it occasionally happens that the fault is a

"reversed" one, that, as in Fig. 43, "hades" under the "up-throw" ones.

We are not, however, concerned with faults to a greater extent than the degree in which they affect the exterior of the globe, and alter the beds of which it is composed, with the result of giving an impress to the scenery. They may, in this way, form cliffs and valleys, though the wearing-down action of the elements gradually smoothes off the irregularities thus formed. It may happen that the two series of displaced beds—the down-throw and the up-throw—are separated by a considerable distance, and the crack between them be filled up not by *débris*, but by mineral deposits. Such "veins" will be considered in another chapter. Or if the rocks are hard, the ends of the broken beds may be polished smooth by rubbing against each other in being shifted up or down. Such an appear- is known as "slickensides." It has sometimes been seen when the thick wall of a house has been cracked by an earthquake and the two sides abraded against each other without the stones being actually displaced. This great as many of those with which we are acquainted. The Runn of Cutch, in the delta of the Indus, is a familiar example of a region which has suddenly subsided, and near New Madrid, in Missouri, a similar depression followed a series of shocks. On the other hand, elevations, equally sudden, have resulted from similar causes. These depressions and elevations could scarcely have been caused without the beds underneath being either bent or ruptured; while the terrible disturbances by which Krakatau, in the Strait of Sunda, near Java, was destroyed in 1883, and others of scarcely less importance with which the last few years have acquainted us, were forcible enough to shatter almost any thickness of strata. Sometimes these dislocations are not only very deep, but extend over an immense extent of country. A fault in Virginia has been traced for more than eighty miles in the same direction as the foldings of the Appalachian chain,* and Von Decken has described one in the southern part of the Carboniferous zone of Liége and Hainault, that extends from the Prussian to

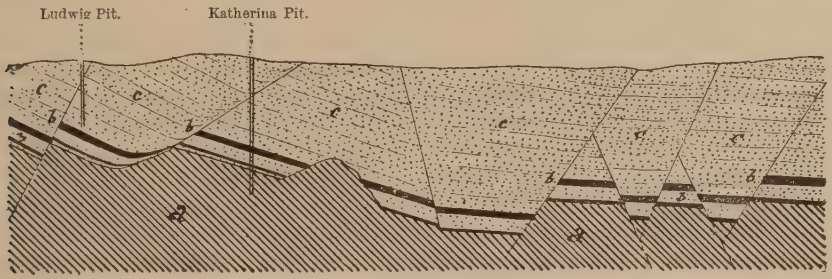


Fig. 44.—SECTION OF THE COAL MINES OF KLADNO, IN BOHEMIA.

(*According to Krejci and Helmhacker*).

a, Cambrian beds; *b*, Coal beds; *c*, Sandstone strata (Upper Carboniferous).

gives us an inkling of the way faults may have been produced.

That these were to a great extent the same subterranean forces which have twisted and bent the strata in the manner already seen (p. 75) need scarcely be doubted. Indeed, within the memory of the present generation, there have been earthquakes and volcanic disturbances sufficient to cause faults quite as the French frontiers, for a distance of 235 miles.

Joints.—At the point where one bed comes in contact with that lying above it or below it, there is, as might be expected, a well-marked line of separation. But in addition to these lines of lamination, there are others which

* Rogers: "Geology of Pennsylvania," p. 897; Suess: "Das antlitz der erde" (1883).

cut across the beds, at right angles to their planes of deposition, and to the horizon and each other, in addition, at all angles. These cracks are called "joints." They are of immense benefit to the quarrymen in raising blocks of stone, which without them would require to be laboriously cut through, as they have a tendency to divide all rocks into square-shaped or cuboidal pieces. These joints can be very well seen in a block of coal. The surface which formed the line of lamination is generally dull, and readily soils the fingers; the cracks at right angles to these are more cleanly, and go by the name of the *face*, the *slyne*, or the *cleat*, in the dialect of the particular district. These divisional planes are no doubt caused by the same action which we see going on when the clay at the bottom of a dried-up pond cracks by contraction in drying. They are also seen in unstratified rocks, like Trap and Granite, and in such cases may be regarded as having been caused by shrinkage in the course of that cooling from a molten state, which such masses have undergone. Sometimes these rocks are so jointed-like, they crumble down like starch into cuboidal or prismatic fragments.

CHAPTER IV.

Unstratified Rocks: Central Heat: Various Forms of Unstratified Rocks.

General Characteristics of Unstratified Rocks—The Interior of the Earth—Three Leading Theories held Regarding it—The Data for Believing that it is Molten—Mathematical Objections to the Doctrine—Arguments in Favour of the other Two—Conclusions from the Facts Mentioned—Granites: their Characteristics, Scenery, Varieties—Trappean Rocks: their Characteristics, Scenery, and Varieties—Grounds for Believing that the Unstratified Rocks are of Igneous Origin.

Hitherto we have been considering rocks more or less arranged in regular beds, and in many cases containing the remains of plants and animals which existed during the time they were laid down. These "fossils" enable us to determine approximately if not their actual, at least their relative ages. But the foundations on which all these rocks eventually rest are others of a massive character, in which no trace of stratification can be detected, nor anything in the shape of a fossil be found. Sometimes they form huge shapeless masses rising up into cliffs or hills, and at other times they constitute wall-like veins and branches through the rocks lying above them, showing that they were originally molten, and had, during some eruption, burst in that condition through the stratified beds. In such a case we can fix to some extent the period of this eruption, though it is perhaps unnecessary to say that this is only in a geological sense, not in a significance which the ordinary chronologer would recognise as at all precise. Such rocks we have already learned to recognise as Igneous, Plutonic, or Unstratified. Granite and "Trap," in their numerous developments, are examples of this great series.

The modern lithologist, aided by the chemist and the microscopist, has divided and subdivided these rocks into endless varieties, to which endless names have been applied. For our purpose something much simpler, if less determinate, will suffice. But before describing the chief forms of these igneous rocks, it may be well to say a few words regarding the source from which they are all but certainly derived, namely, the interior of the earth. At one time it was almost universally held that the centre of our globe was a sea of molten matter, on which the hard surface, which we know as *terra firma*, was superimposed in the form of a thin shell, which bore to the liquid interior much the same proportion that the rind of an orange does to the pulpy matter within it.

This view is now gravely disputed. The main facts which have been ascertained regarding the temperature of the unexplored interior of the earth may therefore be briefly stated.

The Interior of the Earth.

The temperature of the atmosphere is due not only to the heat of the sun, which it has been ascertained penetrates in places to a depth of over 101 feet, but to the temperature of the earth, derived from certain reservoirs of heat at a depth beyond which the miner has not as yet reached. The upper beds of the earth exhibit a very uniform temperature, the warmth from internal sources which they lose by radiation being compensated for by what they gain from the sun's temperature, or, as it is called, *insolation*. At a depth of from five to seven feet the difference between the climate of summer and winter is not marked. In tropical countries like Java it is reached at half that depth, while in middle Europe there is at a depth of from 80 to 112 feet an almost uniform state of the thermometer throughout the year.* In Germany the surface beds, at a depth of 82 feet, have an average temperature of 48·20° Fahr. In the Arctic regions, Siberia, for example—where these observations have for the most part been taken—there is scarcely any variation in the annual temperature. For more than half the year the surface of the earth is frozen to a considerable depth; then during the short summer it is thawed to a depth sufficient to enable a sparse vegetation to grow, while the soil a few feet down is still congealed, as it has no doubt been for ages. In Siberia, in the valleys more especially, it is not uncommon for frozen soil to be found at from 260 to 300 feet, and at Yakutsk (latitude 62° 2′ N.) it extends to 620 feet, though no modern cold could have affected the earth to this depth.

Temperature of the Earth.—That, however, beneath the frozen soil in the North and at a much shallower depth in other regions, there must exist not only warm but even molten matter, is shown by volcanoes vomiting forth ashes, lava, and steam; by the hot springs which rise to the surface in so many parts of the earth; and still more accurately by the observations made in the numerous borings for wells and mines in different parts of the world. Everywhere, after we pass through the narrow zone which is influenced by the varying temperature of the seasons, the heat increases, never diminishes, as we bore into the earth; though, owing to various local circumstances, this temperature is not uniform all over the world, or even in a limited district. Observations in mines, owing to the lights and the presence of human beings emitting warmth, are not always to be depended upon. But, taking the mean of a great many data, the increase of temperature is now generally agreed to be about 1° for every 64 feet in depth. From the tables out of which this generalisation has been formed, what are called *isogeotherms*, or lines of equal underground temperature, have been drawn (Fig. 45). These lines follow, for the most part, the contour of the surface, but are not quite so steep. "Their flattening," according to Everett, "increases as we pass to lower ones, until, at a considerable depth, they become sensibly horizontal planes. The temperature gradient is consequently steepest beneath gorges, and less steep beneath ridges."

This increase of temperature is, however, not always uniform. In the Rose Bridge Colliery, for example, the temperature rose for the first 558 yards at the rate of 1° for 57·7 feet; in the next 257 yards at the ratio of 1° in 48·2 feet, while in the lowest portion of 432 feet it is 1° in 54 feet. The probable reason for these variations may be sought for in the different powers of different rocks to conduct heat, the lighter and more porous rocks conveying heat less readily, while the dense and crystalline ones offer less resistance to its passage. In boring the artesian well of Grenelle, near Paris, it was found that when the temperature of the air was 51·34, that of the water at a depth of 94 feet was 53·6, while

* These observations were made in 1671 by Giov. Cassini, on the temperature of a cellar at the observatory of Paris, and in the year 1783 Lavoisier made experiments which show that at the depth of eighty-nine feet the thermometer indicates 53·06 Fahr.

at 1,802 feet it rose to 82·4. The artesian well from which the fountains in Trafalgar Square, in London, are supplied may often be noticed steaming on cold days, and in one sunk in Kentish Town, in the north of London, the temperature at a depth of 1,100 feet is 69·9, or at the rate of 1° for every 54 feet of descent into the bowels of the earth. At Sperenberg, near Berlin, a series of observations in a boring to the depth of 4,172 feet, for the most part through rock salt, gave at 3,390 feet an increase of 1° for every 51½ feet.

Altogether, taking the different data as yet accumulated into account, it will be seen that they vary so much that the average

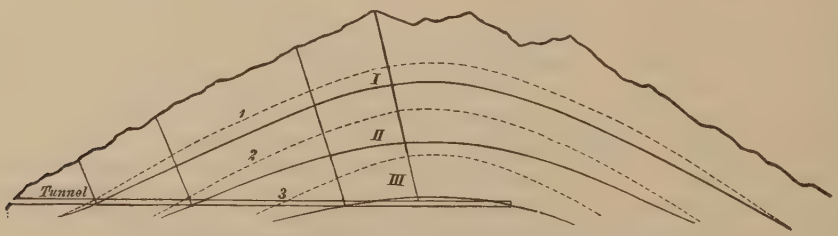


Fig. 45.—ISOGEOTHERMS IN THE INTERIOR OF A MOUNTAIN.

I., II., III., the isogeotherms. 1, 2, 3, the atmospheric isotherms.

descent for every degree runs all the way from 29·7 feet up to 59·6, and even in one doubtful case to 65 feet,* though the mean already given may be accepted as the true one, the observations in the various Alpine tunnels not materially altering the conclusions arrived at from data obtained from the sources indicated. They have, however, established the fact that, as is shown in Fig. 45, the isotherms, or lines of equal temperature along the side of a mountain, follow tolerably closely those of the rocks of which it is composed, though, of course, the figures are not in both cases the same.

Theories regarding the Interior.—It is thus plain that there must exist in the interior of the earth a very high temperature. What this is cannot be clearly decided, since no means more precise than the comparatively ineffective observations already noted exist for estimating the degree of heat in the centre of the globe. But when we see molten matter thrown up, we know that whatever the depth from which this came the heat must have been enormous. Of late years, however, physicists have come to the conclusion that it is not at all certain, or even in accordance with known laws, that the nucleus is of molten material. The main argument in favour of the centre being liquid is that, if the ratio of increase of heat with depth continues as we go downward, at fifty miles in the interior the temperature must be 4,600°, or sufficient to melt almost any substances with which we are acquainted or which are vomited out of volcanoes, while the existence of a thin skin or crust is necessary for the formulation of a reasonable theory of earthquake shocks. On the other hand, the late Mr. Hopkins, Sir William Thomson, and others, hold that the globe is solid throughout, with or without fluid spaces or cavities at irregular intervals, on the ground that were the crust less than 2,000 miles in thickness, the influence of the sun and the moon in producing tides is so great that it would yield to the strain, and be subject to periodical alterations in form similar to those which we see producing oceanic tides. Sir WilliamThomson therefore concludes that the earth is on the whole more rigid than a continuous globe of glass of the same diameter, while Professor George Darwin, after investigating the subject on the same lines, is of opinion that "no very considerable portion of the interior of the earth can even distantly

* Hann: "Zeitschrift der österreicheschen Gesellschaft für Meteorologie, 1878," p. 21.

approach the fluid condition." Finally, a third theory has been broached by Mr. Fischer, by which it is attempted to find a middle course between these opposing doctrines. In this hypothesis—for theory is, perhaps, not quite the exact term to apply to it—the centre of the earth is admitted to be solid, but between this and the upper crust is a "magma" or semi-fused or liquid layer. In other words, as Sir William Dawson has so aptly popularised it, "the earth may be compared to a stone fruit, such as the plum or peach, somewhat dried up. It has a large and intensely hard stone or kernel, a thin pulp made up of two layers, an inner mass dense and dark-coloured, and an outer one less dense and light-coloured. These constitute the under crust. In the process of drying it has slightly shrunk, so as to produce ridges and hollows of the outer crust, and this outer crust is cracked in some places, allowing portions of the pulp to ooze out, in some of these its lower dark substance, in others its upper and lighter material. The analogy extends no farther, for there is nothing in our withered fruit to represent the oceans occupying the lower parts of the surface, or the deposits which they have laid down."

This interior sub-crust is regarded as not perfectly homogeneous, but is considered capable of being roughly divided into two layers or magmas, as they have been called. The upper of them is "highly silicious or acidic," of low specific gravity, and light-coloured, and corresponding to rocks like granite and trachyte. The lower is more dense, less silicious, more basic, and more highly charged with iron; so this corresponds with such igneous rocks as dolomites, basalts, and other lavas of a similar kind. Curiously enough, the recent discovery by Nordenskjöld of native iron in Greenland basalts affords some grounds for believing that the inner magma is in part metallic. Much of the Greenland basalt is impregnated with particles of iron. But Nordenskjöld's great blocks, which he at first regarded as meteoric, were found at Uivfak, on Disco Island. Andrews also found small particles of iron in British basalts. This theory of Fischer has been adopted by Sir William Dawson,* and the conclusions he draws from the data given, are, so far as they bear upon our study, as follows: (1), The nucleus of the earth—to use a convenient expression — is probably solid and of great density and hardness, while the under-crust is plastic or liquid. (2), This plastic sub-crust is not in a state of dry igneous fusion, but in that condition of aqueo-igneous fusion which arises from the action of heat on moist substances, and which may either be regarded as a fusion, or as a species of solution at very high temperature. This we learn from the phenomena of volcanic action, and from the composition of the volcanic or plutonic rocks, as well as from various chemical experiments.† (3), Where rents or fissures form in the upper or solid crust—our *terra firma* so called—the materials of the lower crust are forced upwards by the pressure of the self-supported portions of the former, giving rise to volcanic phenomena either of an explosive or quiet character, as may be determined by contact with water. The underlying material may also be carried to the surface by the agency of heated water, producing quiet discharges. It may also be observed that explosive volcanic phenomena, and the formation of cones, are, as Prestwich has well remarked, characteristic of an old and thickened crust; quiet ejection from fissures and hydro-thermal action may have been more common in earlier periods and with a thinner over-crust. (4), The contraction of the earth's interior by cooling and by the emission of material from below the over-

* It formed the basis of his Presidential Address to the British Association in 1886, and from his lucid remarks much of our summary has been taken. In addition to Hopkins, Thomson, and George Darwin, who maintain the solidity and rigidity of the earth on astronomical grounds, Hennessy, Delaunay, Newberry, and Airy, have discussed the question, and arrived at different conclusions, while Barnard and Crosby, Dutton, Le Conte, and Wadsworth, have taken up the question in America. Durocher has elaborated the theory of "Magmas," though long before the period when any of the authors mentioned wrote, John Phillips gave the first inkling of the idea in his "Manual of Geology" (1855), pp. 493, 564.

† Daubrée: "Études Synthétiques de Géologie Expérimentale" (1879); Tilden and Shenstone: *Philosophical Transactions*, 1884; Crosby: *Proceedings of the Boston Society of Natural History*, 1883; Newberry, *Science*, IX. 91.

crust, has caused this crust to press downward, and therefore laterally, and so to effect great bends, folds, and plications; and these, modified subsequently by surface denudation, constitute, as we have already indicated (p. 33), a certain class of mountain-chains and continental plateaux. Such lines of folding have been produced more especially where thick sediments had been laid down on the sea-bottom. Thus we have here another apparent paradox, namely, that the elevations of the earth's crust occur in the places where the greatest burden of detritus has been laid down upon it, and where consequently the crust has been softened and depressed. Yet Bonney has well shown that an amount of contraction, almost inappreciable in comparison with the diameter of the earth, would be sufficient to produce this description of mountains; and that as the greatest mountain chains are less than $\frac{1}{600}$ of the earth's radius in height, they would on an artificial globe one foot in diameter be no more important than the slight inequalities which might result from the paper gores overlapping each other at the edges.

These, in few words, are the conclusions at which the majority of physicists and geologists have arrived regarding those portions of the earth which we can never reach, and which there is little hope for believing we shall ever be able to learn anything about except by inference. As will be seen, the theories differ widely. But this difference of opinion only demonstrates how indecisive are the facts from which the theorist has to reason, and how science, even when mathematics comes to the aid of geology, will sometimes yield, as an American satirist has remarked with as much truth as humour, "a large return of hypothesis for a small investment of fact."

If this is a fair exposition of the state of belief regarding the interior of the earth, the views which are entertained on the subject of the earth's crust must be equally vague, since the conclusions must entirely depend on what estimates are made as to the rate of cooling of the molten nucleus, or indeed whether the primeval world was ever a molten ball. Numerous estimates have been made, though they vary so widely as to leave a doubt as to the soundness of the premisses from which inferences so vague have been deduced. Arago puts the thickness of the crust at 22 miles; Humboldt reckoned it at from 8 to 10 geographical miles; Elie de Beaumont at 28 miles; and Lyell at 34 miles. Cordier, on the other hand, estimated it at from 64½ to 148 miles, while, as we have seen, Hopkins considered the globe as, for the most part, solid, the minimum thickness of the crust being in his opinion not less than from 800 to 1,000 miles. But whatever opinion is entertained, it is yet clear that some part of the earth—whether the central regions or cavities here and there in the crust, or that more mythical sub-crust with its two magmas—must be in a fused condition. This is evident from the liquid and heated materials ejected by volcanoes, and from the fact that in every case these materials are identical with those which form one great section of the unstratified rocks. To melt these rocks requires, we know from experiments, a temperature of from 3,500° to 5,500°, so that the central heat must be at least as high as this (p. 84). Beyond this it would be idle in a work of this nature to go, and merely puzzling to narrate all the doctrines which have at different times been held, or are still held in individual instances on this much-discussed question. One geologist, for example, argues that the molten centre of the globe must be composed of iron, the residue of the endless "meteoric stones," which dropped into it in those remote ages when it was liquid, an hypothesis which has gained ground, though not precisely in the direction indicated by this author, from the discovery of large masses of iron (p. 85) in basalt.

Be this as it may, there need be no manner of doubt that the unstratified rocks are derived from the molten matter. In form they differ widely. Numerous names have been applied to the different varieties, owing to the difference they show in chemical composition, and in the arrangement of the minerals of which they are composed. But, for the purpose of the physical geographer, they may be broadly divided into (1) the Granitic and (2)

the Trappean series. Of the one granite is the type; of the other the ordinary greenstone, or the various rocks of that nature which are known as "Trap," may be regarded as good examples. Under these heads, therefore, we shall find little difficulty in saying all that need be said concerning the unstratified or igneous rocks.

The Granitic Rocks.

Every one knows granite by name, and except to the inhabitant of the flat plains and low deltas it can hardly fail to be familiar by sight also. It forms the material out of which so many monuments are constructed, roads paved, and important buildings reared, that specimens of some of its varieties, especially the grey and red, can be seen in almost every street, in even the most remote country towns. The Grampians are composed of it, and the city of Aberdeen is, for the most part, built of this long-enduring rock. The mountains of Cumberland, Devon, and Cornwall, the Wicklow Mountains in Ireland, the Alps of Switzerland, the Dovrefields of Norway, the Pyrenees of Spain, the Ourals and Himalayas of Asia, the Andes of South America, the Abyssinian Mountains of Northern Africa, the central chain of the great island of Madagascar, and the hills of Damara Land, in South Africa, are all composed of granite, or have been materially affected by its intrusion among the sedimentary rocks which lie above it. In piers, and docks, and lighthouses, granite plays an important part; and even when decomposed, the Kaolin or China clay, composed of the silica and alumina which enter into the composition of the granite of Cornwall and Devon, forms an important article of commerce. The potter seeks the felspar for the manufacture of the finest crockery and other objects, and the manure manufacturer the aptatite or crystallised phosphate of lime traversing it in veins, while among other products associated with granite — not to include many "accessory" minerals — mica, meerschaum, cairngorm (or the amber-coloured varieties of rock-crystal), asbestos, beryls, and other Oriental stones, may be mentioned.

Granite, moreover, enters largely into the features which make up scenery. Firm and unyielding, except to the long-continued action of the weather, granite cliffs have a tendency to keep these forms whenever they take the shape of cliffs, the softer beds which have been upreared in time wearing away, unless when hardened by contact with the molten intrusive mass from below. Yet owing to the poverty of the soil, produced by the decomposition of the elements of granite, the regions in which it prevails are on the whole dreary, being for the most part devoid of wood, and when in the shape of moorlands, even more hopelessly barren than such tracts usually are. In many cases it forms bosses and huge rounded hills, with, as Dr. Page very justly remarks, little regularity of outline,so that the granitic scenery is more monotonous than that of the trappean rocks, owing mainly to the fact that while the latter are quite as unyielding to the weather, so far as decomposition is concerned, they break off in endless cubical fragments, always exposing fresh surfaces to the air, and thus giving to cliffs of this rock that stair-like appearance which has suggested for the principal member of the series a name derived from the Swedish *trappa*—a stair.

Still, from its widespread occurrence and durability, granite enters extensively into the formation of some of the noblest scenery of the world, from that of the sublime Andes to the widely different — but, notwithstanding, strangely impressive—wilds of Dartmoor and the neighbouring Cornish country. On its shoulders rests, as on a framework, a vast array of strata of different ages, though it is for the most part associated with the oldest class of sedimentary rocks. Yet, in the Pyrenees it penetrates beds of the same age as chalk; in Saxony one of its varieties overlies the chalk at Weinböhla; in Ireland a like relationship is detected; and among the earliest observations of Mr. Darwin was one to the effect that the granite which forms veins through some of the strata of the Andes must have been fluid as late as the Tertiary period, since it has contorted and altered the beds with which it came into contact. Mont Blanc and Mont St.

Gothard are mainly built up of granite. The high Tatra of the Carpathians owes its majesty to the same rock. The Riesengebirge, the Erzgebirge, and the Karlsbad, as well as the Fichtel Mountains, the Bohemian Forest, and the Harz, are also granite. But some of the most notable granite scenery is that supplied by the magnificent Yosemite Valley, which forms one of the chief attractions of the Sierra Nevada of California. The granite pinnacles and domes of the highest Sierra opposite Owen's Lake are fine, but the Yosemite, with its lofty cliffs and waterfalls, is generally admitted to form the grandest of the Western landscapes. The Yosemite Valley Professor Whitney describes as 3,950 feet above the sea, and hemmed in by cliffs ranging from 2,000 to 3,000 feet in height. But what distinguishes it from all other known valleys is, first, the near approach to verticality of its walls; secondly, their great height not only absolutely, but as compared with the breadth of the valley itself; and, finally, the small amount of *débris* at the base of these gigantic cliffs, the fact being due, as we have seen, to the resistance of granite to weathering of the kind which so speedily crumbles a sloping "talus," as it is called, at the foot of trappean cliffs like those of Salisbury Craigs, so well known a feature of Arthur's Seat at Edinburgh. The "Pohono," or Bridal-Veil Fall, just in front of the Cathedral Rock, the first conspicuous object in proceeding up the valley, is about 3,000 feet high; and on the other side is the Tutucanula, or "El Capitan" cliff, an almost perpendicular mass, 3,300 feet above the level of the valley (Fig. 46). Then come the Cathedral Spires, two slender columns of granite, and, two miles higher up, the groups of peaks to which the name of the "Three Brothers" has been given. The highest of these is 4,000 feet in height, and more than 8,000 feet above the level of the sea, and standing over against the group is a cluster of cliffs, one of which, 3,000 feet above its base, has been called the "Sentinel Rock." "The Dome," 4,150 feet high, is another remarkable granite cliff in this singular dell. Nor are the waterfalls one whit less extraordinary. The Yosemite Creek, in descending from the cliffs on the north side, leaps over precipices, in one case with a vertical drop of 1,500 feet. The Nevada, or Merced Falls, of the Merced River, which flows through the whole length of the valley, are wonderfully grand, the latter having a perpendicular height of 639 feet, the river descending more than 2,000 feet in a distance of five miles.

Above the Yosemite the immense granite knobs or domes of the High Sierra are remarkable features in the scenery. Mount Dana, more than 13,000 feet in height, dominates the region above the Yosemite, whilst Mount Whitney, 14,887 feet above the level of the sea, the highest peak in the range, and probably the loftiest in the United States—unless, indeed, Mount St. Elias, in Alaska, is entitled to that distinction—forms another elevated piece of granitic scenery.*

Varieties of granite.—The appearance of granite is so well known as scarcely to require any description. It seems, when a sharp face is exposed, to be composed of an aggregation of crystals, compacted in varying degrees of density from specimens in which they are so loose as to be easily separated, to others in which it is difficult to break the stone which they unite to form. Quartz, felspar, and mica are the names of these minerals. They are always sharply crystallised, never with their angles worn as if they had rolled in water or been subjected to other abrading influences. Sometimes—most often, indeed — this rock is found in huge shapeless masses, but not unfrequently it takes the shape of veins, or "elvans," as they are called in Cornwall, which penetrate other rocks, and even different varieties of its own kind.

As we have already learned, granite is for the most part found bursting through or penetrating with its veins strata as old as the Silurian, the cases in which these ejections are contemporary with the more recently formed beds being entirely exceptional. Hence we are entitled to class granite as the oldest of

* Whitney: "Guide to the Yosemite Valley" (1875); "Geological Survey of California," Vol. II.; Cronise: "The Resources of California" (1868).

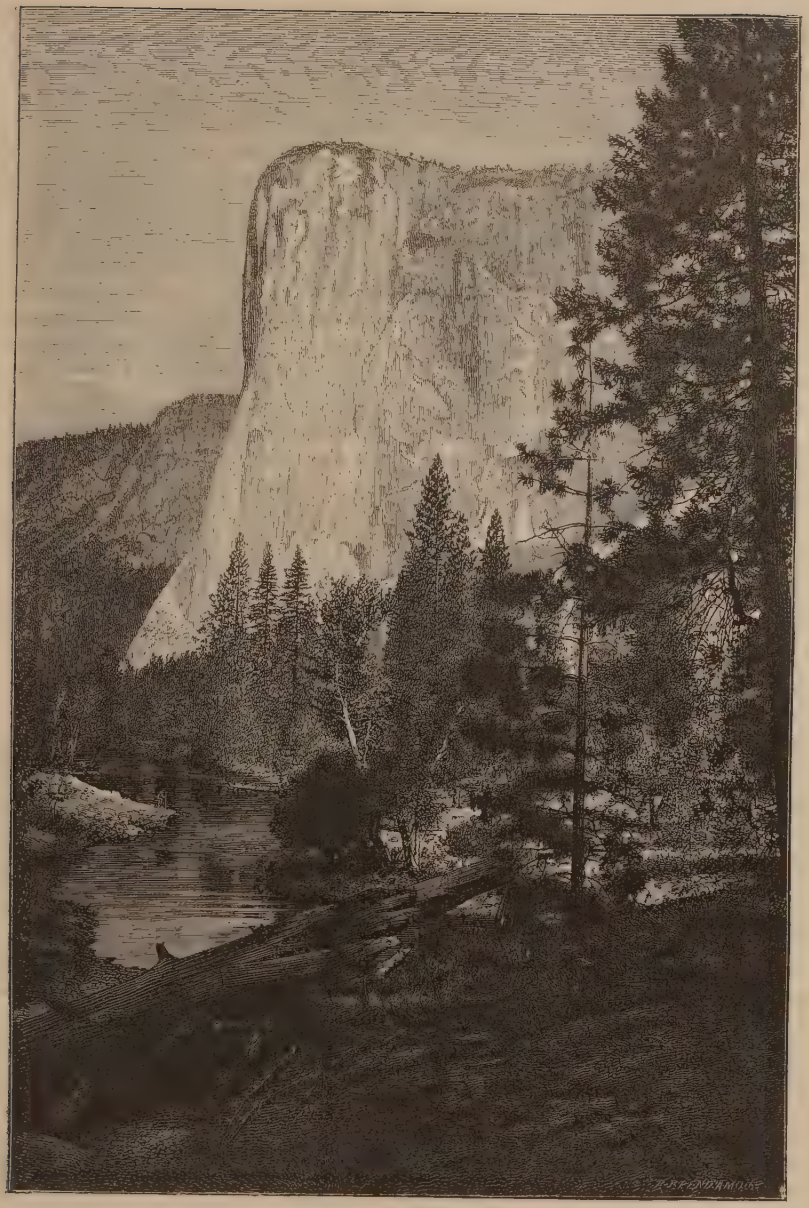


Fig. 46.—"EL CAPITAN," A GRANITE CLIFF IN THE YOSEMITE VALLEY, SIERRA NEVADA, CALIFORNIA. 3,300 FEET ABOVE THE LEVEL OF THE VALLEY.

(*After a Photograph.*)

the igneous rocks, traps—as we shall learn presently—intruding into beds of newer age.

In appearance the typical granite is greyish. When dusky white, felspar predominates; when reddish, the materials have been coloured by iron.

Syenite is that variety of granite in which the mica is replaced by orthoclase and hornblende, a mineral of a darker hue, while *Syenitic granite* is a form in which mica and hornblende are present. *Porphyritic syenite* is a rock where large crystals of felspar are imbedded in a small-grained syenite, this variety being in demand for monuments and other decorative purposes. Again, *Zirconian*, *hypersthenic*, and *diallagic*, are distinguishing terms applied to syenite, in which the minerals zircon, hypersthene, and diallage replace either wholly or in part the quartz or the hornblende, while *pegmatite* is a form in which orthoclase, felspar, and quartz, are arranged in lines, which—as in the "graphite-granite," or "Lapis Judaicus"—give it an appearance, when polished, of being covered with Hebrew characters. In *Eurite*, the ingredients are blended into a fine granular mass, and in *protogine* talc supplants the mica. There are various other varieties characterised by the greater or less amount of particular minerals present, or by the number of simple minerals which make up their substance, the terms binary, ternary, and quaternary being applied, according as two, three, or four minerals enter into the composition of the rock. Such distinctions are, however, more for the chemist and the mineralogist than for the geologist proper, since there are many gradations, and several such varieties may be found within a few feet of each other, without the circumstance having any direct bearing on the facts of physical geography which a study of the cliff or hill is calculated to elucidate.

All of the forms of granite have certain common characteristics in addition to those already mentioned. For instance, unlike many of the trappean rocks, they are never vesicular, that is, full of cavities; nor tend to form columns, like basalt; and being more crystalline and compact, they are regarded as having been formed at greater depth and under heavier pressure. For this reason the term plutonic, as distinguished from volcanic, is sometimes specially reserved for them, though more frequently it is used as the common property of all the igneous rocks.

In Scotland the whitish-grey granite is specially mined at Rubislaw, the bluish-grey at Cairngall, and the reddish-hued variety at Peterhead, Aberdeen being the centre of their manufacture into various architectural objects, while from the West of Scotland and England, and Shap Fell in Westmoreland, various porphyritic kinds are introduced. It may be remarked that the Cornish granites are mostly grey, while the others which constitute their chief rivals in commerce, namely, those of Scotland, tend more to red. In London we see the two in conjunction on Waterloo Bridge, where the coping-stone is composed of the latter variety, while the balustrades are constituted of the former. On the Continent we find porphyritic granite in abundance all the way from Elbogen to Karlsbad, in the Karlsbad Mountains, and near Wunsiedel in the Fichtel Mountains, where the large masses of orthoclase crystals which give character to this description of rock are popularly known as "Karlsbader Zwillinge," or Karlsbad Twins. The Vienna "plasterstein" is a grey or yellowish granite with large crystals of orthoclase, and is found exposed in, among other places, the quarries at Mauthhausen, between Lenz and Krems on the Danube. Another variety, which has been called *granitite*, composed of red orthoclase, with green oligoclase, quartz, magnesia, mica, and sometimes hornblende, is found in the Riesengebirge, at the Brocken in the Harz, and at Baveno on Lago Maggiore; that at Assouan (Syene), in Upper Egypt—which was at one time regarded as the typical syenite, and was extensively employed in the construction of the ancient temples and obelisks of that country—is a closely-allied variety (p. 91).

Protogine appears in the Alps at Mont Blanc, in the St. Gothard, and other localities, while pegmatite—with tourmaline, epidote, garnets, beryls, topazes, and other minerals imbedded—

is seen at Theusing, in the Karlsbad Mountains, at Wottawa, in the Bohemian Forest, and at Bodenmais, near Zweifel, in the Bavarian Forest. Graphic granite may be studied at (among other places) Bodenmais, in Bavaria, and Lomnitz, in the Riesengebirge, near Pressburg.

The typical *Syenite* (that of Syene is, we have seen, more of a granitite than a true syenite) is found at the Plauenscher-Grund, Dresden,* in the Erzgebirge, in Moravia, between Brünn and Blansko, in the Alps, in the syenite rock of Monzoni in Tyrol, in the Vosges, in Bulgaria (Vitosch, near Sofia), and other places; the porphyritic forms have very much the same distribution.

Granitite and syenite also form the material of many of the isolated ice-borne blocks scattered over the country; and *Luxullianite*—a curious variety of granite never yet found *in situ*—may be mentioned as the material out of which the Duke of Wellington's sarcophagus in St. Paul's Cathedral is hewn. Granite in weathering—that is, crumbling down under the long-continued action of the elements, as every rock must do to a greater or less extent sooner or later—often does so along the lines of joints, so that, as in the "tors" of Cornwall, or in the rock sketched in Fig. 47, they look like rude Cyclopean ruins. The "loggans," or rocking-stones, are also specimens of granite weathering in another shape. These rounded boulders, though weighing many tons, are so finely poised as to sway backwards and forwards on the slightest impulse. Though it is quite possible that some of them may be artificial, yet, as they occur in nearly every country and always in the same position, it is all but certain that in the majority of instances they are natural. They may have originated in a tor-like mass, or in a series of cuboidal blocks, such as in Fig. 47. Then the felspar and other decomposable ingredients being washed away by the rain, what was formerly a solid pillar becomes, by a gradual process of decay, either a heap of spheroidal masses piled one upon the other, or a single boulder resting on the more massive rock below. In most cases the equilibrium of these piled-up boulders is not retained. The base crumbles and they tumble down. But should a mass so crumble away that in spite of the gradual diminution of its point of support the balance is kept, a rocking-stone is the result. A superstitious feeling attaches to many of them, and having been used either as sepulchral monuments (as in Greece) or as means of divination—the number of vibrations determining the answer to be given by the oracle—the idea has arisen that all of them were artificial. The great loggan of Land's End, in Cornwall, has been estimated to weigh more than 90 tons. This, like a similar one, the "Buckstone" in Monmouthshire, was overturned by some mischievous idlers, but

Fig. 47.—THE "MITTAGSTEIN" IN THE RIESENGEBIRGE.
(Showing granite weathering along the joints in cuboidal blocks.)

* Syenite, formerly applied to a rock in which mica is replaced by hornblende, is now by most lithologists restricted to one in which orthoclase and hornblende unite (sometimes with augite, plagioclase, biotite, or augite), to make a granular rock such as that at the Plauenscher-Grund, to which Werner first applied the name, though at a later date he made it out to be a greenstone. This rock is, according to Dr. Geikie, found in Raasay, Skye, and Antrim, where it has penetrated Jurassic rocks, and is itself probably of older Tertiary age. The rock of Syene, which we have indicated as more like granitite, is by this geologist looked on as syenite-granite. It is also found in many parts of Scotland, Skye, for example, where it has invaded and altered the Lias beds.

was eventually replaced at an immense cost of time, money, and labour. One situated at Islandmagee, on Brown's Bay, in Ireland, is by the superstitious people in the neighbourhood believed to acquire a rocking, tremulous motion at the approach of malefactors and other heinous sinners. Finally, it may be added that when granite weathers in such a manner as to leave boulder-shaped masses on the summit of a hill, these collections of rocks are known in Germany as a "Felsenmeer," or Sea of Rocks. Such a one occurs at Felsberg, in the Odenwald.

Trappean Rocks.

"Trap" was at one time a term applied to any igneous rock, tolerably compact, and of a newish date, which was not granitic. It was, as Professor Bonney very aptly remarks, a "traveller's term"—one used legitimately when a more precise one was impossible. In roughly grouping the unstratified rocks, therefore, it may be usefully retained to describe the entire group of which the "whinstone" of the North Country people is the type, though the specialised labours of petromicroscopists have succeeded in dividing them into a number of classes, one of which slides almost insensibly into the granitic. Indeed, the rock near Dresden, which Werner at one time classed as syenite, was afterwards assigned by him to the dolorites (p. 91). This transition is clearly shown in the bust of Rameses in the British Museum. Though composed of one continuous mass of rock, the head, as Richardson pointed out many years ago, is of syenite, or granitite, while the body is of undoubted greenstone. Yet, though the lithologists may cavil at any such broad distinction between this order of rocks and the one which preceded it, the physico-geographer can rarely have any difficulty in the matter. The Trap series are, in general language, lavas which have been vomited out of ancient volcanoes, for the most part under water, and are in the majority of instances associated with strata of a newer age than those through which granite bursts. Otherwise their mode of occurrence is not widely different. They intersect the stratified rocks in the shape of veins, which often harden into wall-like upright seams ("dykes"), or overspread them in the form of sheets, or pour out on the surface into rounded knolls. Indeed, these trappean rocks have been one of the powerful agents in disrupting and altering the stratified rocks through which they have been erupted in a molten condition. The scenery of a trappean country is, as a rule, more picturesque than that of a granite one. The step-like terraces, so characteristic of Trap, and the tendency to crumble in more or less cuboidal fragments, give variety to the cliffs of this rock, even when it does not rise in the form of conical hills; while the rich soil usually produced from the wearing-down of all volcanic rocks, combined with the easy drainage afforded by their many joints, renders the regions where they rise to the surface unusually fertile, and, therefore, more thickly peopled than one more barren. The trappean rocks also assume more varied forms than the granitic, and though the hills which they enter into the composition of—the Welsh, Derbyshire, Cheviot, Lammermoor, Ochil, Pentland, and most of the Irish ones, for example—are rarely so lofty as those of granitic origin, they gain in capability for human occupation what they lose in Alpine grandeur. Add to this that when the traps tend to take a columnar form they give a remarkable feature to many of the show places of the world, Fingal's Cave (Fig. 48), Samson's Ribs, on Arthur's Seat, near Edinburgh, and the Giant's Causeway, in Ireland, being among the most familiar types of this form of "basalt."

As nearly every secondary district is disturbed by trappean rocks, there is no difficulty in finding examples of the different varieties. The "road-metal," with which the highways are macadamised, is most probably, if not granite or flint, some form of trap. The "cobble pavements" of some old-fashioned towns are almost invariably of this rock, and in districts like that in the vicinity of Innerleithen, in the south of Scotland, the houses are commonly built of these unattractive-looking rocks. They have been employed for sculpture, some of the Hindoo, Persian, and Egyptian works of

art being hewn out of the close-grained greenstones and basalts, while from the cavities in the "amygdaloids" of the north of Scotland and the Rhine are obtained those "Scotch pebbles" now so extensively used in jewellery. Mineral veins are not common in the trappean series; but there is one notable exception in the plates, strings, and blocks of native copper which permeate so many of the traps in the vicinity of Lake Superior, and have been found in Alaska and on the shores of British Columbia, though there, as in the traps of Dumbartonshire, the metal is distributed too sparingly to render what has as yet been unearthed of any commercial importance. On the shores of Lake Superior, however, vast fortunes have been accumulated by the fortunate rediscoverers of these virgin veins. Yet, before they lit upon the mines, the ancient workings show that some aboriginal race, who have left behind them no other records than their rude stone tools, had ages ago been busy raising the lumps of precious metal. At the Cliff Mine, on the Kewecnaw Peninsula, there are tunnels hewn in the solid copper, some of the masses which have been hacked out by manual labour weighing as much as eighty tons. In the old workings were found numerous stone mauls and hammers, gads, gouges, and chisels made of stone and copper, which the prehistoric miners had left behind them when they abandoned the working of these rich deposits fully four centuries ago.*

Generally speaking, the traps are widely different from the typical granites, though the more divergent forms of the two series might easily be mistaken, even when they do not run into each other. But when we range over their numerous and puzzling varieties, it becomes impossible to assign any brief character by which they may be distinguished. Some, like basalt and greenstone, are close-grained and crystalline, while the trap-tuffs and so-called claystone-porphyries are soft and earthy. Nor does the guide which their mineralogical structure supplies afford any surer ground for their classification. Augite, felspar, and hornblende are the principal minerals which enter into their composition; though hypersthene, olivine, quartz, clay, iron, and green-earth, are also found in varying quantities. Their physical structure is almost equally varied. Some, for example, are vesicular, full of air-bubble cavities, like the lavas; loose and cindery, or scoriaceous, like volcanic ashes; brecciated (p. 52), like the accumulations around volcanoes; columnar, like

Fig. 48.—FINGAL'S CAVE, ON THE ISLAND OF STAFFA, OFF THE WEST COAST OF SCOTLAND.
(Showing basalt taking a columnar form.)

* Wilson: "Prehistoric Man" (1876), Vol. I., pp. 198-228. Page: "Economic Geology" (1875), p. 73.

many basalts; compact, like the hornstones, and so forth.

Again, the terms applied to these rocks have been rather loosely employed. For instance, the word "porphyry" was originally used to describe the dark red or purple rock of Djebel ed-Dokhan, in Egypt, so largely used by the Romans for decorative purposes. In time the word became to be employed to designate almost any rock in which one prominent mineral was imbedded in a more compact and felsite-porphyry, or pitchstone-porphyry, of the Triebisch Valley (Tribischthal) in Saxony, and the island of Arran in Scotland.

The *Melaphyre group* is another rather vague term, though it is generally understood to apply to dark, compact rocks of "considerable geological age," and defined as normally consisting of "felspar, augite, and iron-peroxide," though in reality some of these rocks are porphyrites and others only very ancient basalts.

The *Trachyte group* is more natural and

Fig. 49.—"DER BORZEN," NEAR BILIN, IN BOHEMIA—A PHONOLITE HILL.

matrix; so that we had porphyritic granites and porphyritic traps. This vague nomenclature ought to be abandoned, for, as Professor Bonney very properly remarks, the word porphyry does not sufficiently describe any particular rock, though the adjective porphyritic may be usefully applied to designate a structure in which isolated crystals appear prominently, and are probably the remains of a former state of solidification which have survived the last melting down of the rock.

Hence, we have porphyritic granite in the shape of the mass which presents the great orthoclase crystals called "Karlsbad Twins" (p. 90), and the entire porphyry granite which comprises, among other rocks, quartz-porphyry better defined, consisting of rocks which show a coarse cellular paste, rough and gritty to the touch, comprising quartz-trachyte, rhyolite, phonolite or clinkstone—such as we see in the "Borzen," a hill near Bilin, in Bohemia (Fig 49), and which is so called from the clinking or metallic sound which it emits when struck with a hammer,—obsidian, and perlite—those glassy lavas hardly distinguishable from artificial glass-slag, of which the ancients made looking-glass, and which many savage races use to this day for the fabrication of arrow-heads, knives, axes, and other cutting-tools. Greenstone is another familiar term which has of late years fallen into disfavour with the stricter school of lithologists. Like felstone,

it used to be included among the basalts; but it is now taken to indicate the more compact diorites, diabases, and slightly decomposed basalts; while felstone, according to Dr. Bonney, includes the felsites, porphyrites, and perhaps, accidentally, some phonolites.

Then there is the *Basalt group* proper, which comprises dolerite, a form of greenstone composed of felspar and augite, usually with some intervening trace of other minerals such as olivine and iron-peroxide.

The term basalt, at one time applied very vaguely, is now retained for a rock in which the constituents mentioned are so minute that the mass is black. There are various varieties of it into which we need not enter, though the columnar form which gives so marked a feature to the scenery of the world is, perhaps, the best-known form.

Dolerite, in the shape of nepheline-dolerite, is seen in the Katzenbuckel of the Odenwald; leucitophyre is exhibited near the summit of Mount Vesuvius, &c.; while a small horny-looking variety, called anamesite, is seen in numerous other localities, such as the old volcanoes of Bohemia, the extinct group of volcanoes in Auvergne, and in Scotland, Ireland, &c. Basalt—which in this case, as we have seen (p. 85), contains metallic iron discernible by the microscope, besides nickel, as in the blocks found on the Greenland shore—is seen in the nepheline form at Niedermendig on the Rhine, in the leucite variety in the Albanian mountains near Rome, in the Eifel, and at Schackau on the Rhone. Many mountain chains are composed of basalt, as the Auvergne in France, the Eifel in Central Germany, the Westerwald, the Vogelsgebirge, and, not to enumerate localities the very names of which would fill many pages, the Giant's Causeway at Antrim, the Island of Staffa with Fingal's Cave (Fig. 48, p. 93), the scarcely less remarkable columnar structures of Skye, Ailsa, and Morven; the Käsegrotte (Cheese Grotto) at Bertrich-Baden, half-way between Trèves and Coblenz (Fig. 50); or the columnar pillars on the hill-sides of Vicenza in Italy.

The *Diorites* are, by some geologists, made another group. In ordinary language they may be described as varieties of greenstone, and owe their dark colour to the disseminated plates of hornblende, of which they are composed, in addition to felspar. Different varieties of it are found in Moravia, in the Sudeten, in the Erzgebirge, in the Island of Corsica (where a variety called napoleonite exists), in the Bohemian forest, in the Karlsbad mountains, in the Fichtel mountains (near Wölsau), as well as in Egypt, between the Island of Philæ and Assouan (black porphyrite), where it supplied much of the material out of which the ancient statues were hewn.

Diabase, another gradation from dolerites and basalts, in which a chloritic mineral and generally a little calcite is present, is in Germany found in the Harz, in Nassau, Saxony, in the Fichtel mountains, in Bohemia, near Kuchelbad, as well as at Prague and other localities. Its extreme beauty has caused it to be employed in the arts, its green colour, due to the chlorite, contrasted with the crystals of felspar, having given it the name of green porphyry or "porfido-verde," by which it is known to artists.

The *Porphyrite group* may be reckoned another sub-section of the dolerites, though with the limitations already mentioned (p. 94). In all of them we see the structure alluded to. Quartz-porphyrite, or felsite-porphyrite, is a light, rather reddish mass, where quartz and orthoclase crystals make up the mass. It is found in large quantities near Botzen in South Tyrol, in Saxony near Leipsic, and Halle, where it forms basins, as in the Thuringian Forest. The amorphous, glossy form of felsite is known as pitchstone, such as we see in the Island of Arran, at Meissen, and in the Triebisch Valley in Saxony. Porphyrite proper is usually of a dark colour with brownish-red or brown solid masses, which contain crystals of oligoclase mixed with hornblende and mica. It is found in Saxony in the Thuringian Forest, in Scandinavia, and in Egypt at Djebel ed-Dokhan (p. 94), which was the locality whence was derived the ancient red porphyry, or "porfido rosso antico," so valued by the Romans.

The *Gabbros** (or diallage rocks) of the Islands of Mull and Skye, of the Volpersdort in Silesia, of the Harz, and other localities (including Northern Italy), are coarsely crystalline masses closely allied to dolerite.

Fig. 50.—THE CHEESE GROTTO AT BERTRICH-BADEN.

This brief description of some of the principal varieties of the trappean rocks may suffice for our purpose. Modern mineralogists have, of late years, lavished an enormous amount of industry, and no slight degree of ingenuity, in attempting to classify them by their chemical composition, and by the arrangement of the minerals entering into them, as revealed by the microscope. Yet it is seldom that any two of these students agree on any leading classification. The forms so merge into one another, and have suffered so many local and other transformations, either during their original eruption or subsequently, that it is doing the reader little service to introduce him farther than the doorway to

* The word *gabbro* is Italian. The French mineralogists know it as *euphotide*, and artists as *Verde de Corsica*, under which name it is employed in the fine arts.

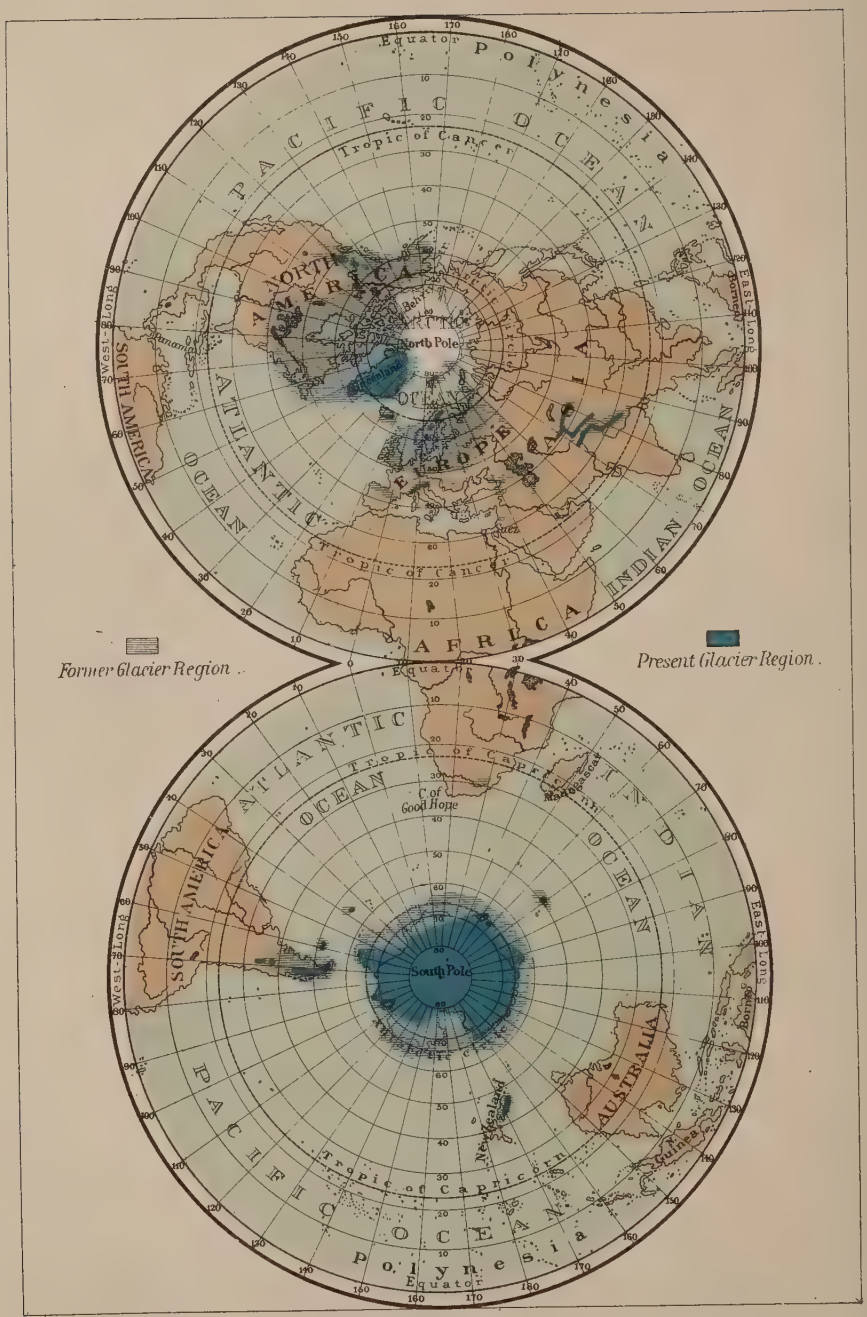


CHART SHOWING THOSE PARTS OF THE EARTH FORMERLY AND AT PRESENT COVERED BY GLACIERS

(AFTER Dr ALBRECHT PENCK)

these laborious researches. Even the simpler attempts to roughly group them according to their age into the granites, which are, as a rule, the oldest of all; into the trappean, which are of later appearance; and into the volcanic series, which are at present in course of formation, or have been vomited out of the "bowels of the earth" in comparatively recent periods of the world's history, even these attempts fail to stand the test of criticism. For, apart from a doubt as to the granites deserving the place of honour as regards antiquity, it is not difficult to find the match of every trappean rock in the vast masses of lavas and other *débris* shot out of the crater of any of the active volcanoes of our times. Indeed, to use the words of Sir James Hall, "the analogy between the two classes"—the ancient and the modern igneous rocks—"seems to hold through all their varieties; and I am confident there is not a lava of Mount Etna to which a counterpart may not be produced from the whinstones of Scotland." This brings us to inquire what has been the origin of these igneous rocks.

Origin of the Igneous Rocks.

That the igneous rocks owe their origin to fire is clear from various considerations. In the first place, the perfect resemblance which so many of them bear to the melted matter poured out by volcanoes goes far to suggest that they must have had a similar origin. But when we examine the way in which they occur, this suspicion becomes an absolute certainty. They do not, as is already known, lie in regular beds, but are either heaped up in shapeless accumulations on the surface, or poured in among the stratified beds, either by these beds having been formed after the eruption of lava took place, or by the erupted matter bursting through the strata in the line of least resistance. In the latter case we see the offshoots of the igneous rocks taking the form of wall-like partitions, or "dykes," as they are called, penetrating long distances through the beds, or branching in tree-like masses of less regular form. But wherever the igneous rocks burst through the strata above them, they not only tilt, fissure, and generally dislocate the beds in the manner already described, but indurate and otherwise alter the parts they come into immediate contact with for a considerable distance on either side. Thus, the limestones and chalk become crystalline marbles; sandstones are changed into white cherty rocks, called quartzites, and some shales into porcelain-jaspers, and even hornstone; while in the vicinity of granitic veins new minerals are frequently developed.

Granite.—The igneous origin of the granites is not at first sight quite so evident, though from the typical grey granite there are all

Fig. 51.—DIAGRAM SHOWING GRANITE INTRUDING AMONG STRATIFIED ROCKS.

gr, Granite; *k*, Crystalline schists.

gradations until the typical trappean rock is reached, so that it is difficult to separate the causes to which the one is due from those to which the others are attributed. It is true that we do not find those columnar and

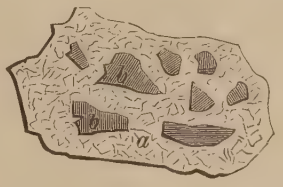


Fig. 52.—SECTION SHOWING FRAGMENTS OF HORNBLENDE IN GRANITE WHICH HAS ENVELOPED THEM DURING AN ERUPTION OF THE MOLTEN ROCK.

a, Granite; *b*, Hornblende.

spheroidal structures which, in the case of the trappean rocks, point so distinctly to their having been cooled from a state of fiery fusion. But the granites, like the other igneous rocks, exhibit the eruptive features on which we have already commented. Like them they burst through and branch out into tree-like masses among the stratified ones (Figs. 51, 52, 53, 57). And not only do they intrude in

this way, but granite veins are not unfrequently intersected by veins of granite newer than themselves, and wherever they come in contact with softer beds the dykes and veins of granite alter, generally by hardening, the rocks on either side. Still, the varied features

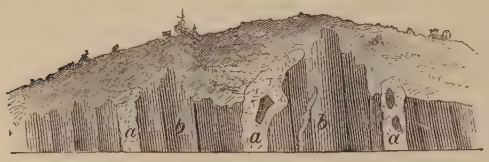


Fig. 53.—GRANITIC VEINS OF APOPHYSES AT SANGERBERG, IN THE KARLSBAD MOUNTAINS.

a, Granite veins; *b*, Hornblendic schists.

which the granites possess, and especially their very sharply crystalline particles, have led to hot discussions regarding their origin. At one time the entire geological world was divided into Wernerians and Huttonians, or, as they were sometimes called, Neptunists and Vulcanists. The one set of theorists were the disciples of Werner, for long the head of the great mining school of Freiberg, in Saxony, who taught that all the phenomena exhibited in the earth's crust were to be attributed to the operation of water, to the utter exclusion of an agent so clearly manifest as fire. The Huttonians, on the other hand, placing their faith on the sounder reasoning of Dr. Hutton, a Scottish physician, enunciated a theory of the world the reverse in all essential points of that advocated by the German mineralogist and his school, for though they did not exclude the action of water and atmospheric agents in forming the sedimentary rocks, they pointed out that these had been consolidated by heat, and that many of them had been altered by the long-continued action of the same agency. But, above all, the Huttonians not only declared that the igneous origin of the trappean rocks was obvious, but that the granites were crystallised from a state of fiery fusion at great depths in the earth, under pressure so vast as to have prevented the gases generated from escaping, and thus to have enabled them to assume their present crystalline structure. In brief, the Huttonian doctrines, modified and extended by the researches of the present century, are essentially those held by the modern geologist.*

But though the Vulcanists have long ago supplanted the Neptunists in the hierarchy of science, they made a stout fight for their ancient supremacy. In Edinburgh especially, where Dr. Hutton lived, and Professor Jameson, the principal exponent of the opposite doctrines, taught, the controversy waxed so hot that it took an almost personal turn. Paris during the closing years of the *ancien régime* was not more stoutly divided by the rivalries of the Gluckists and Piccinists; or the Holy Roman Empire, four hundred years ago, by the conflicts of the Guelphs and Ghibellines, than was the Scottish capital when the nineteenth century was young by the bitter controversies of the Neptunists and Vulcanists. They did not go to war, certainly, though there are traditions of hot words and threatened conflicts in a day when even philosophers wore swords; and when a play from which greater things were expected failed to receive the approbation of a critical audience, its friends declared that because it had been written by a Wernerian, "it was damned by a packed house of Huttonians."

Still, though this is now rather ancient history, the ideas which formed the central point round which the discussion was warmest have left their mark on geological thought, even up to our own times. Lithologists of a certain type of mind—the mind which can only see one set of phenomena at a time—may even yet be found dwelling with longing love on the "aqueous condition of formation" which granite has undergone. The principal arguments in favour of the non-igneous origin of granite are that it contains certain minerals that could not have existed in a state of fusion in the presence of free silica without combining with it, and that some of the accessory minerals in granite would suffer change by an elevation of temperature; while, if the

* Playfair's "Illustrations of the Huttonian Theory" (1802).

crystals had been fused, it would scarcely have been possible for them to contain water, as they occasionally do. However, as Mr. Rudler suggests, it is possible that, in most instances, these minerals are of secondary origin, and have been produced by the alterations of the granite after it has cooled from the primitive condition of fusion. Moreover, the mere presence of water is not incompatible with the received origin of granite, for David Forbes declares that specimens of lava taken from a current in Etna while the lava was still flowing contained crystals of stilbite, a mineral holding 16 per cent. of water in its composition. Even in the quartz of volcanic rocks there are little cavities containing water. But unless we adopt Dr. Haughton's hypothesis that the rock, after having been poured into dykes and veins when in a state of fusion, has been altered by the action of water of a high temperature, the position in which granite is found debars us from accepting any explanation of its origin except an igneous one. Indeed, the narrowness of the fissures into which it obtrudes itself points conclusively to the mass having been completely molten when it forced its way through the rock in which it forms veins, and not simply a viscous paste, as has been suggested. Of late years there has been a tendency to regard granite not only as in no degree older than the trappean rocks—since the rule that it is found for the most part penetrating the more ancient stratified deposits has so many exceptions—but even as an altered stratified rock. That is, it is sometimes a very much transformed or "metamorphosed" description of gneiss, which gneiss is again considered an altered sedimentary formation—the gradation being so gradual. Such speculations may, however, be regarded as more ingenious than sound, and, in any case, scarcely admit of being received in the present state of knowledge.*

It is, however, certain, from Mr. Sorby's observations, † that granite has solidified under vast pressure, the microscopical structure of its constituent minerals being in every respect analogous to that of those found at great depths and ejected from modern volcanoes.

Traps.—There is thus no reasonable doubt that both the granitic and the trappean rocks are of igneous origin, and that their varied and often perplexing texture is to a large extent due to the varying rapidity with which they have cooled—the same mass becoming an obsidian-like block when suddenly cooled, a basalt when heat is withdrawn more slowly, and an earthy or imperfect crystalline one when the cooling goes on still less rapidly; while the columnar structure of basalt was proved by the experiments of Gregory Watt to be due to the pressure of numerous spheroids on each other in the act of cooling. It was as if a number of cannon-balls were piled on each other and then melted: the pressure of these spherical bodies on one another producing a columnar shape very similar to what we so frequently see in the rock in question.

The extinct volcanoes found in all parts of the world afford ample evidence of the identity of the causes which have been at work in producing the modern and the ancient igneous rocks, while the outbursts of the modern ones are almost equally to the point. Many of the ancient basalts, we have seen, are barely to be distinguished from the modern lavas, either in structure or in the minerals which are embedded in their interstices and substance, and when opportunity occurs the modern igneous rocks, equally with the ancient ones, intrude into the neighbouring strata and alter their texture at the points where they come in contact with such beds. Nor are data of a similar character lacking for an identification of the origin of granite. For though no volcanoes of modern times—or even of a period which geologically there is any reason to pronounce comparatively recent—vomit forth granite, this rock so insensibly graduates through granitite and syenite into greenstone and basalt, that it is not stretching a point to pronounce all the igneous rocks of a similar origin—that is, they have been derived

* Ramsay: "Physical Geology and Geography of Great Britain" (1878), p. 42. Green: "Geology," p. 307.

† *Quarterly Journal of the Geological Society*, Vol. XIV., p. 453

from the interior of the earth. But whether there is a fused zone under the structure, composed of two "magmas," a vast liquid sea occupying its centre, or a series of hollow cavities filled with such material, it is not in our power to affirm with any approach to confidence. "Time," quoth Sir Thomas Browne, "hath endless rarities and shows of all varieties; which, reveales old things in heaven, makes new discoveries in earth, and even earth itself a discovery. That great antiquity, America, lay buried for thousands of years, and a large part of the earth is still in the urn unto us." A great deal has been ascertained since the Norwich physician wrote his "Hydriotaphia." But in our day as in his, "in the deep discovery of the subterranean world, a shallow part" must perforce limit the investigation, if not satisfy the curiosity, of the inquirer.

CHAPTER V.

Dykes: Mineral Veins: Concretions: Metamorphism.

Dykes—Their Nature—Trap Dykes—Granite Dykes—Elvans—Mineral Veins—Their Contents—Their Mode of Deposition—Something about the More Interesting—Concretions—Their Nature and Formation—Metamorphism—Its Various Kinds and its Influence in Altering the Character of the Rocks Subjected to it—Cleavage—Foliation—Geological Maps.

While studying the subject of dislocations in strata we saw that frequently fissures of varying breadth were produced. Sometimes these fissures were filled up by *débris* derived from the broken beds. But it is also evident that they may be occupied by materials which have infiltrated into them from other sources, and it is equally clear that in the eruption of molten material from below, the granitic and trappean rocks must not only disrupt the beds through which they burst, but form—in the shape of these tree-like masses which they assume—not only veins, or "apophyses," but actually walls or dykes of solid material. These dykes form, therefore, the theme of a short explanation.

Dykes.

Trap Dykes.—These wall-like sheets of lava are seen where we have an opportunity of examining any modern volcanic cone. But though it might be rash to say that such intrusions were either more frequent or of greater extent in former periods of the world's history, we see them to greater perfection, though identical in kind, when the beds of which the earth's crust are composed are examined. The igneous character of such dykes is shown by the rocks through which they burst being baked and altered on each side. The coal is converted into cinder, the slate into jasper or Lydian stone, or into a rock very like porcelain; the soft sandstone into hard rock, or even half-fused into a crystalline mass known as quartzite; while, as in the Giant's Causeway, the chalk in immediate contiguity to the trap dykes is altered into marble, a change which will occur, not if chalk is burnt, but if heat is applied under such an amount of pressure as to prevent the escape of the carbon dioxide—or, in more familiar language, carbonic acid—which, in union with lime, makes up the rock mentioned. Sometimes these dykes form perfectly straight walls, so that when the softer rocks on each side wear away under the action of the elements, the dyke will often traverse the country for miles as a more or less unbroken wall, which by the uninitiated might easily enough be, as indeed they have been, mistaken for an artificial fence. On the shores of the Waigat Strait, between Disco

Island and the Noursoak Peninsula in Greenland, such a dyke is a marked feature in the landscape, the soft sandstone and coal beds having left it standing out bold and isolated on the face of the hill close to Atenakerdluk, so familiar to geologists as the locality in which the remains of the semi-tropical plants are found, showing that in comparatively recent times a mild climate prevailed in a region where icebergs are never out of the voyager's sight, and a night of three months shrouds the land in darkness.*

These dykes vary in breadth. Sometimes they are not more than a few inches wide, while, as in one intersecting the Dudley coalfield, they may be 420 feet broad; or 134 feet broad, as in the remarkable one near Plas-Newydd in Anglesea; or fifty or sixty feet broad, as in the Cleveland dyke, which runs from near Whitby in Yorkshire to Cockfield Fell, a distance of nearly sixty miles. As likely as not, they proceed far down into the interior of the earth to some central mass of the same rock as that of which they are composed, though

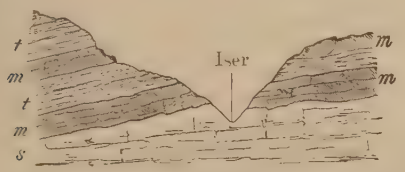


Fig. 54.—SECTION OF THE ISERTHAL NEAR OBER-SITOWA, BOHEMIA.

s, Lower New Red Sandstone; *m*, Intrusive sheet of Melaphyre; *t*, Triassic clay slates.

now hardened, since, unlike what is found in modern volcanoes, the ancient igneous forces of the under world no longer find a vent through the places where in former periods of the earth's history the lava was so plentifully discharged (Fig. 55). In many instances the dyke branches, or sends intrusive sheets horizontally among the stratified beds (Figs. 54, 56), or expands itself on the surface in the form of a boss-like hill (Fig. 55). Indeed, the modes in which the erupted rock breaks through the strata over it, may vary according to any given physical circumstances which might at the

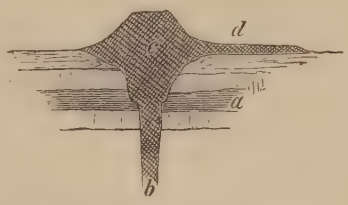


Fig. 55.—DIAGRAM OF A VOLCANO.

(Showing a Dyke-like "Neck," ending in a Boss (or Crater), and sending a Shoot over the Sedimentary Strata through which it has burst.) *b*, Dyke; *c*, Boss; *d*, Overspreading Sheet; *a*, Sedimentary beds.

time have influenced or controlled it, the tendency of the molten lava being to find a path to the surface along the line of least resistance.

Dykes very frequently take the line of faults, the molten matter having occupied the fissure thus produced, and as often as not greatly enlarged it. When the rocks on either side of the dyke are soft, they wear away and leave the harder wall of trap standing isolated. However, this is not invariably the case. For, as in Arran, where there are dykes penetrating hard sandstones, the intrusive trap has crumbled away, while the rock through which it has burst remains proof against the weather, and the place formerly occupied by the dyke is open for a considerable distance. Or, if the dyke is on either side in contiguity with a rock which it has indurated for a considerable distance outward, this rock will resist the weathering influences better than the dyke itself, and last, long after the trap, which has hardened it has disappeared, in the shape of two walls following the line of the fissure between them. This also is seen in the Island of Arran, and other parts of Scotland.

Granite dykes though perhaps not quite so familiar as trappean ones, are still sufficiently common. This rock not only bursts through other rocks, but, we have seen, branches out in numerous twig-like veins, which sometimes cross one another, and, like trap, appear on the surface in the form of bosses or domes,

* Brown: "Geology of Disco Island and the Noursoak Peninsula" (*Transactions of the Geological Society of Glasgow*, Vol. V., pp. 55—115.)

as in the Islands of Skye, Mull, and Arran, which Professor Judd has shown were the cones of old volcanoes. From these central masses there can be traced in various directions

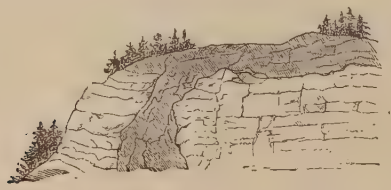


Fig. 56.—DYKE OF MELAPHYRE AT ZDERETZ, ON THE PARDUBITZ-TURNAUER RAILWAY IN BOHEMIA.

(Showing the Dyke Overflowing on the Surface in the shape of a Sheet.)

spurs and dykes which "exhibit every variety of structure from coarsely crystalline granite to the vitreous substance of lava." Moreover, these dykes, we learn from Mr. Jukes-Browne, are connected with lava-like sheets of rhyolite and trachyte, which occur round the flanks of the mountains, thus confirming the belief that, though the granite was consolidated under a great thickness of overlying rock and actual lava stream to its source within the bowels of the earth, we should in all probability be able to mark in its course every gradation, from pumice or obsidian to actual granite." *

Elvans.—In Cornwall, the local term of "elvans" is applied to quartz-felsite in veins, this rock differing from granite mainly in the absence of mica. But in reality the word is loosely used to express very fine-grained granite, or, as Mr. Rudler most properly remarks, is applied to almost any rock which occurs in a dyke running through "killas" or clay-slate. In the accompanying diagram (Fig. 57), some of the main facts discussed in the preceding pages are portrayed.

Mineral Veins.

The word vein, as contradistinguished from dyke, is usually understood to express a wavy rather than a straight course of the fissure with its contained matter. But in reality the distinction is not strictly adhered to, many mineral veins or lodes being rectilineal. It is,

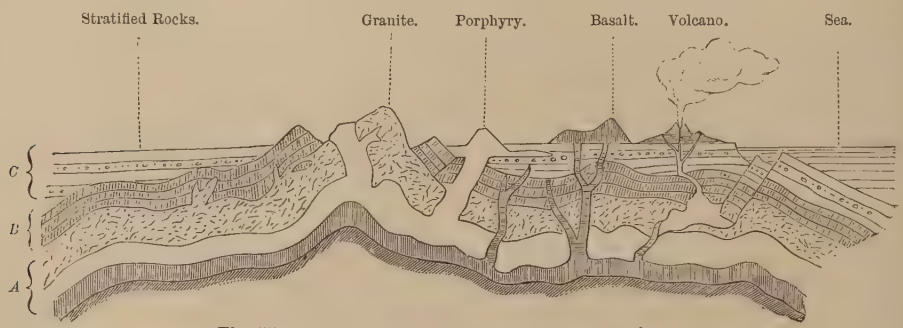


Fig. 57.—IDEAL SECTION THROUGH THE EARTH'S CRUST.

A, Eruptive (Igneous) Rocks of different ages; *B*, Crystalline Schists immediately overlying them; *C*, Clastic Beds of different ages.

rarely came to the surface by means of volcanic vents, they were the "basal reservoirs of ancient volcanoes, and the parent masses from which actual lava streams have proceeded." The gradation of the one into the other has already been noticed, and, many years ago, the late Professor Jukes, one of the most acute of observers, hazarded the opinion that "if we could follow any

however, easy to divide them into two great groups—those in which the contained matter does not appear to be derived from any central or extraneous mass, but is confined to the rock in which they occur, and those which do not originate in the rocks through which they

* Judd: *Quarterly Journal of the Geological Society*, Vol. XXX.; and "Volcanoes," p. 142 (Jukes-Browne, *l. c.*, pp. 422, 423).

run, but derive their origin from some source in no way connected with it.

The first class are often exceedingly fine, and form a perfect net-work. They are probably cracks into which the matter which now fills them—be it quartz or carbonate of lime *—has infiltrated by "segregation" from the surrounding rocks. We have already seen something of the other class when speaking of the igneous rocks, though those with which we are immediately concerned are the fissures of this type containing mineral matter, in various chemical combinations, mingled with or imbedded in a matrix of material different from the rock through which the vein runs. This material may be derived from some central mass, though recent investigations have gone far to show that these veins might not have been veins of intrusion, but, as Mr. Tate puts it, the metalliferous deposit may have arisen without any original fissure by a slow metamorphic action gradually replacing the original rock-constituent. However, in most cases where metallic veins pass through various rocks, they were originally fissures made by faults, or shrinkage of the rock, and kept open—as they often are in hard rocks—or widened by the entrance of water. In other

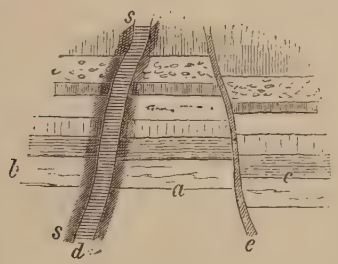


Fig. 58.—VEINS.

One vein (*d*) occupying a crack in sedimentary strata, the other (*e*) taking the line of a reversed fault; *s*, Wall rock; *b*, *a*, *c*, Displaced portions of the beds.

cases the veins may have been—before they became the repositories of minerals—cracks, joints, or any of the other fissures with which our previous studies have made us acquainted (Fig. 58).

Relation of Direction and Contents, etc.—Many attempts have been made to eliminate the various exceptional circumstances which are found in certain veins in order, if possible, to formulate a law connected with their origin and distribution. Hitherto these efforts have not resulted in any very marked success. Still, we are able to say that some relation exists between the contents of the metalliferous veins and the course in which they run. For example, the lead lodes of Cornwall and Devonshire take a north and south direction, while those which run east and west contain tin and copper ores, and, in British Columbia, gold-bearing quartz veins take a similar course. It may also be said, in general terms, that most of the lodes from which the chief supplies of ores are obtained permeate the oldest set of beds in the earth's crust; for, though the gold quartz of California, Central America, and Peru is found in "secondary" beds, this metal, in Australia and most other countries—the Oural Mountains, for example—is confined to reefs traversing "palæozoic" strata, chiefly of Lower Silurian age. As the auriferous quartz is richest in the vicinity of eruptive rocks, it may not unreasonably be assumed that when the reefs are found in the younger beds—as in California—their presence may be connected with the intrusion of diorite or other igneous rock. But whatever the thickness of the mineral vein—whether a mere thread, or, as in the great ironstone lode of the Red Mountain, near Schwarzenberg in the Erzegebirge, 40 to 50 feet thick, for a distance of fully four miles—the minerals it contains are usually in a crystalline form—quartz, carbonate of lime, fluor-spar, or barytes, this being termed by the miner "gangue" or vein-stuff, his object of search being of course the ore imbedded in it. Sometimes the vein-stuff occupies the greater part of the space, the ore occurring either in "nests" or "strings," or as scattered crystals, though frequently the walls of the vein are coated with a crystalline layer of some substance; on this

* Quartz—or rock crystal in its purest form—is silica, and cannot be scratched by the nail, while calcite, calc-spar, or carbonate of lime can. The latter, moreover, effervesces or "fizzes" if a drop of strong acid is dropped on it: the other is unaffected by this rough test.

another coat of other crystals is superimposed, and so forth, the "mineral" or ore being in the form of a stripe in the middle (Fig. 59).

A vein is thus, to recapitulate, a separation in the continuity of a rock, of a tolerably determinate width, but extending indefinitely in length and depth, and filled with various substances different from the rock itself, which substances are usually sparry and crystalline, and contain metallic ores. The most frequent materials of this vein-stuff are common quartz and carbonate of lime, in the veins filled spaces hollowed out of the rocks, and which are called by the Germans "stockwerk,"* in allusion to the different floors on which in such cases mining may be carried on.†

But the more common kind of mineral veins are those worked by vertical shafts, and may be regarded as the results of mechanical violence. They may be of all widths and depths, and extend through every kind of rock, stratified and unstratified, holding, however, a determinate course for many miles, and passing through rocks of very varied mineral

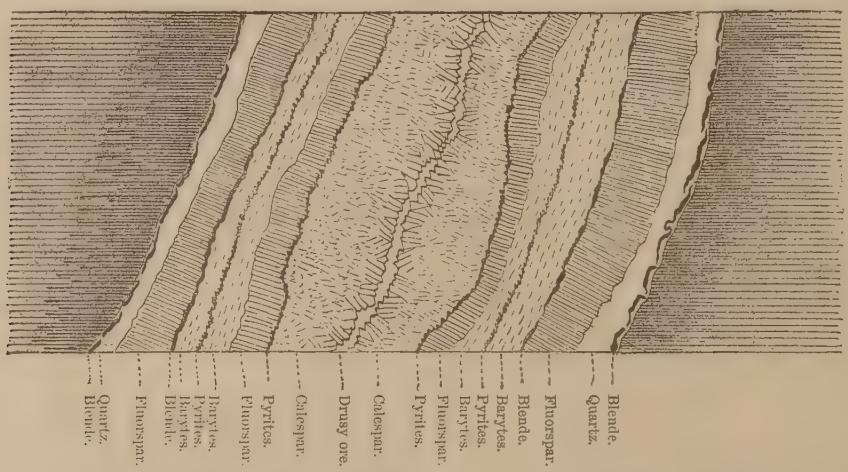


Fig. 59.—THE "DREI-PRINZEN" VEIN AT FREIBERG.

(Showing the Vein Matter in Symmetrical Layers or Bands.)

penetrating igneous rocks. The vein-space may be formed in any of the ways mentioned, though not unfrequently it is due to shrinking of the hard rock during drying, or, in the case of an igneous ore, in cooling from a high to a low temperature. After this, the silicious, calcareous, and metallic substances found their way into these empty spaces by infiltration from the surrounding rocks. Mixed with hot water and steam, metallic ores may have permeated the mass until they reached these receptacles, formed by shrinkage or by other causes; or getting into cavities in the rock formed in much the same way, they may have given rise to that irregular assemblage of metal-composition. The Great Quartz vein of California can be traced for a distance of eighty miles, though, like all veins, it varies much in productiveness in different parts of its course. Occasionally we find a vein, say, of tin, broken by a fault, the space formed by which is filled, say, by copper, and even a secondary, tertiary, or quaternary dislocation of the same kind by which the different lodes

* These seem much the same as what are known in the North of England as "pipe veins" or "flat veins."

† Lyell's "Elements of Geology," pp. 589—602, from which many of the facts mentioned in this section are condensed, contains, so far as a text book can, an admirable summary of the state of knowledge on this subject, which more recent researches have done little to modify.

have been repeatedly dislocated; until mining in a locality such as Huel Peever, at Redruth, requires an intimate acquaintance with the geological structure of the district.

That veins have been disturbed after being filled is seen by some of them having a fissure down through the middle of their contents, the sides of which, where in contact, are polished, or scored with parallel furrows, in the way we have lately learned to know as "slicken-sides" (p. 81); and that many of them at one time opened on the surface is proved by the not unfrequent occurrence of rolled pebbles in the veins, these pebbles corresponding to those on the neighbouring superficial alluvium. Marine shells have also been disinterred at great depth in metallic veins, and a madrepore has been found in the heart of a compact vein of cinnabar (the ore of quicksilver) in Hungary. These facts point to the vein having been opened by an earthquake or other terrestrial disturbance while the rock which it traverses was under the sea. There is also evidence which renders it more than probable that the veins, after having been gradually filled, have not only been opened, but on successive occasions enlarged. What is more, we find many veins alternately contracting and swelling, though, as a rule, the two sides of a metalliferous vein are nearly parallel over a wide extent of country. The contrary is, however, the case in others, the variations in breadth running in a few feet all the way from one or two inches to eight or ten feet. The explanation of this peculiarity is to be found, as Sir Henry de la Beche put it, in the fact that the sides of a vein are sometimes more or less wavy. In such a case, if the opposite sides of an irregular fissure of this character slid upon each other in the way the facts mentioned prove must often have happened, then all manner of spaces, narrow and broad, will be the result. This can be readily demonstrated by dividing a sheet of paper vertically by means of a wavy line; then slide the cut edges up and down: the result will show that the space between the edges will be of very varying breadth as the concavities and convexities come opposite to each other, or the contrary, according to the chance results of the terrestrial disturbance exemplified by this movement of the contiguous edges representing the walls of the veins.

Most veins are tolerably perpendicular to the surface, just as most faults are. But they may slope at different angles; in such a case the upper side of the vein is known to miners as the "hanging" wall, the lower as the "lying" or "foot" wall. When the lode is tortuous, it generally happens that at the place where it departs from the vertical it is choked with stones, or, as miners put it, is "nipped," the ore being at such a point small in quantity, on account of the space being preoccupied by the *débris* in question. On the other hand, when the lodes are wide they are usually filled with earth and fragments of rock, through which the ores are disseminated; these detached pieces of rock are frequently coated or encircled by metallic substances, and are known as "horses" or "riders." Finally, that we should find some veins which split into branches is only natural; for the same fact holds true regarding the non-metallic fissures, which are considered of identical origin.

No very constant law has as yet been deduced regarding the occurrence of veins, or as to the conditions under which they are to "twitch" or close their walls, or "belly out" into wider expansions. However, when the vein traverses a succession of strata—and it is perhaps unnecessary to say that they always cut across the beds, and are in no case connected with the lines of deposition — it has been noticed that in the shales and sandstones they are narrowest, and, perhaps, owing to the infiltrating water acting more easily on lime than on the materials of which the other rocks are composed, they are widest in limestone of any "country rock"—the country rock being that through which the veins run.

The contents of mineral veins, according to the manner in which the vein-stuff is disposed, are spoken of as "massive," such as barytes, when no definite arrangement of the contents can be traced; as "drusy," when the vein is made up of cavities filled with crystalline minerals; as "banded and comby" (Fig. 59), when

the opposite wall-faces are covered with comb-like layers, sometimes exactly duplicated; as "brecciated" when fragments of the neighbouring rock are mixed among the ores (p. 105); or as "filamentous," where the minerals are dispersed, as often happens in thread-like veins. The ore may, however, occur in various forms. Gold is, for example, disseminated through quartz, often in grains so fine that they cannot be detected with the naked eye, but after the rock is crushed have to be caught up by coming in contact with quicksilver, the quicksilver of this amalgam being then driven off by heat, when the more valuable metal remains. Again, these patches may be in the form of considerable masses, or "nuggets," the gold found in the beds of streams being simply the metal which has got freed by the crumbling down of the original quartz rock, and washed into the places where it is the "digger's" business to separate it from the sand and gravel by water or other means. Sometimes, indeed, the gold is found in "pockets" in the rock in the shape of beautifully crystallised moss-like masses, and in various other forms. Copper is also occasionally lit upon in this form, though it is usually in strings, bunches, or branches, when in the native strata (p. 93). But, like most other metallic ores, it is more generally mined as a chemical compound—a sulphate, a carbonate, or some such compound.

These ores are usually arranged in parallel layers (Fig. 59) alternating with the vein-stuff, or occupying, as is the case with pyrites and sometimes with galena (the ore of lead), the entire space of the vein, though the instances in which more than one ore is present are more frequent. It is also a subject of common observation that when a vein runs through several different kinds of rocks, it is richer in particular ores. Galena, for example—in the North of England, at least—is most abundant in the limestones, and scant in the shales; and in Cornwall and Devon, where the "country rock" happens to be granite and slate, it has been observed that when crossing the one the veins yield iron, and copper when they traverse the other. That the veins, since they were formed, have served as the channel through which water has infiltrated, is proved by the rock through which they pass being considerably decomposed, and the vein-matter being recrystallised into various minerals.

All of these facts—and we have not mentioned more than the leading ones—invite a discussion of the causes which have been at work in filling these fissures in the earth's crust with the deposits described.

How mineral veins have been filled.—The theories at present held fall broadly into two divisions. The first of these affirms that mineral matter in the veins has been derived by a process called "leaching," that is to say, it has been dissolved out of the adjacent rocks and then re-deposited in the vein-fissure. The second of these theories contends that the ores have been brought up from great depths by mineral springs, in which they have been dissolved; or in steam; or by sublimation, just as the vapour of sulphurous acid "sublimates" into brimstone round the mouths of volcanoes; or after they have been melted by fire, and then ejected into the vein-cavity just as if they had been lava.

In reality, there is a good deal to be said for both theories, and most probably veins have been formed in both ways, though the source whence the mineral matter itself has been derived is by no means so patent. That in the great majority of cases—indeed, in all but exceptional instances—it has been in solution, and subsequently deposited from this watery solution, is clear. But it is evident that the rock through which the vein runs has had so marked an influence on this process of precipitation that it is not always possible to say whether the mineral matter has not been "leached" out of "the country," though in a few cases we are able to say that the materials have been ejected into the fissures in which they lie through the agency of hot water. This has sometimes been the case in California, albeit the vast amount of the gold and other mineral deposits of that State cannot with any

certainty be referred to this mode of origin.* The discovery by Professor Sandberger of small quantities of silver, lead, copper, nickel, cobalt, bismuth, arsenic, antimony, and tin, in minerals such as olivine, augite, hornblende, and mica—all of which are found in igneous rocks—points to these rocks as the sources whence lodes have derived their riches. Dr. Le Neve Foster is also inclined to believe that other lodes owe their origin to a gradual substitution of valuable minerals in the place of some of the contents of a worthless rock, perhaps by hot springs laden with mineral matter dissolving out these worthless materials and depositing in their room the more valuable ores with which they are laden. For instance, in the Great Flat Lode near Redruth in Cornwall, there is a slight fissure. But the "country" on either side of it consists of a rock impregnated with ore, the mineralised part of which fades away into the adjoining rock without there being any distinct wall. It is, however, more than possible that had the fissure here been broader the mineral would in time have been dissolved out of the granite in which it is contained, and transferred to the fissure.

Ore in masses, etc.—Finally, it ought to be added, that it is not always possible to exactly distinguish between the different kinds of mineral deposits here described. Some minerals are in beds, like iron-ore, copper-bearing shales, lead-bearing sandstone, silver-bearing sandstone, and diamond-, gold-, and tin-bearing gravels. But in every instance the materials thus laid down appear to have either infiltrated the beds after their deposition, or to have been washed out of deposits formed in some other manner, such as the gold got in "placer" diggings by the decomposition of the quartz, or the tin got by streaming, by the destruction of the vein in which it originally lay.

Occasionally also, as in the case of the red and brown deposits of hæmatite—a native oxide of iron,—the ore may occupy "pockets" or "churns" in the rock. The "ore-chambers" of so many of the Utah and Nevada mines—the "Eureka" and the notorious "Emma," for example—are also examples of these irregular masses of mineral. The calamine—carbonate of zinc—deposits of Altenberg in Sardinia, and the Iron Mountain and Pilot Knob of Missouri, may also, according to Dr. Foster, be taken as instances in point. The lead found in the sandstone beds of Mechernich, and the silver in the sandstone of Utah, were in all likelihood deposited with the sandstone, having been worked out of the decomposed rock in which they originally lay by the river or the sea waves to which these sands owe their origin, though, of course, they might also have been introduced by solutions percolating through the beds.

Concretions.

In various rocks we find extraneous substances, neither minerals nor fossils, sometimes of an origin contemporaneous with the rock itself, at other times the result of subsequent segregation. These concretions are most abundant in sedimentary rocks, though they are also found in those of igneous and metamorphic character.

Nodules.—These are of great variety, from the iron pyrites—the "diamonds" of sulphate of iron—which are found in so many sandstones and clay-slates, to the great nodules, or "septaria"—those flattened nodules of calcareous clay, ironstone, or other matter divided internally into "numerous angular compartments, by reticulating fissures," mostly filled with calcareous spar, which show well against the darker matrix of the nodules. These reticulating "septa," or processes, arise most probably from the shrinking of the mass while in the act of consolidating, the cracks having been subsequently filled by limy matter infiltrating into them (Fig. 60). These argillaceous, calcareous, and iron-impregnated nodules are common in many clays and marls, such as those of London and Oxford, and in various coal shales in the form of bands. They are usually more or less flattened, and

* J. A. Phillips: *Quarterly Journal of the Geological Society*, Vol. XXXV., p. 390; *Philosophical Magazine*, 1868, 1871, 1873, and 1874; and his treatise on "Ore Deposits (1884), p. 73.

generally contain some organic nucleus—such as a leaf, a shell, a scale, or a coprolite—which give them the popular name of beetle-stones,

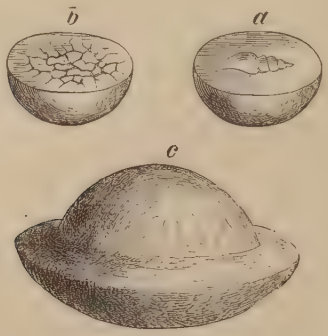


Fig. 60.—CONCRETIONS.

a, With the cast of a shell in the interior; *b*, With septaria or cracks filled with calcareous matter; *c*, Globule of sphærosiderite from the coal shales of Steierdorf in Croatia.

turtle-stones, and so forth. The septaria derived from the London and Oxford clays, when burnt and ground, are used in the manufacture of Roman cement. The term sphærosiderite is a term applied to concretions of siderite or sparry carbonate of iron, which takes the shapes which have suggested for it the miner's name of "kidney iron ore" (Fig. 60).

Geodes.—This word was at one time very generally used to describe these nodules of hardened clay or ironstone, which were "hollow within and filled with soft earthy ochre," or had "a free nucleus or kernel, which rattled when the nodule was shaken." * They were the "aëtites," or eagle-stones of the ancients. But the term is now more generally restricted for the purpose of denoting all rounded nodules having internal cavities, either empty or with a kernel, or lined with crystals, which under the name of "potato-stones," "cat's-heads," and other equally appropriate names, attract the attention of the rustic.

In sandstones under limestones are often found great hardened masses, due to the percolation of water into the lower bed, which has the effect of binding together the particles of sand with which it comes in contact more tightly than the other particles composing the rock. When a layer of loose sand is subjected to this influence the result is, of course, still more marked, and in those portions of France where suitable "road metal" is rare, the country people are in the habit of probing such sandstone beds in order to extract these nodules for the purpose of breaking them up to macadamise the highways.

Thunder-stones.—In England the country folk know the flint arrow-heads of the ancient inhabitants, which they dig up in their fields, as "thunderbolts," and in other places the word is employed to designate the fossils about which the geologist has a great deal to say, under the name of belemnites. But in some parts of Germany the name is bestowed on the nodules found in the cretaceous "Quadersandstein" mountains of Reichstadt, in Bohemia, and other localities. These "Knallsteine," or "Knallkugeln," are of various sizes, from that of a gun-flint to that of a walnut, and present on the outside a ferruginous crust, though internally formed of sand. They lie in the coal, and as they explode by the ignition of the contained gases, may, unless the greatest care is taken, be productive of no small danger.

Penny-stones.—In clay ironstone, nodules varying from the smallest size to pieces of considerable magnitude, and known as pins or penny-stones, are often observed, the concentric cores of which are so loose that when struck with a hammer they rattle, leaving a hard central mass in this core, consisting of carbonate of lime or carbonate of iron, or small crystals of sulphide of zinc (blende), in the manner already described as existing in septaria. In many clays "marcasite nodules"—balls consisting of that variety of iron pyrites, and not unfrequently enclosing a fossil shell or plant—are common, though they also occur in some limestones, such as in the Lower Chalk of Folkestone, where Mr. Jukes-Browne thinks they may have been produced by the conversion of certain silicious sponges, called ventriculites, into iron pyrites. Indeed, the connection of iron pyrites with decaying organic matter is so constant—the marcasite nodules in clays being always more abundant

* Page: "Handbook of Geological Terms (1865).

when organic remains are numerous—that it may be taken as a rule that such nodules are due to the decomposition of plants and animals.

Potato-stones.—These are dolomitised, or altered pebbles of limestone, hollow internally, and with their cavities lined with crystals of bitterspar. Mr. Green regards the cavity as due to the contraction which the limestone has undergone in being converted into bitter-spar.

Flints and chert.—The only difference between these two is that the latter is more opaque than the former, and has its silica mixed with some calcareous matter. They are sometimes classed as concretions. But when we come to study the Chalk formation we shall find that though flints are not, as sometimes popularly described, "fossil sponges," they are really due to the silica contained in the spicules of these sponges.

Phosphatic nodules, often erroneously called coprolites, are found in some clays, and in sandstones and limestones, as ancient as the Lower Silurian. In the Gault formation, in the chloritic marl, &c., these nodules contain 60 per cent. of phosphate of lime, and are therefore of great economic importance as materials for the manufacture of manure. In Canada (p. 56), the nodules found in the Lower Silurian beds, and containing fragments of shells, are believed to be coprolitic, that is, the nucleus was the excretions of long-departed animals.

Concretions in Igneous Rocks.—Concretions are, however, not confined to sedimentary rocks, where it does not require any great acumen to detect how they might have been formed. They are found in igneous ones, though much less developed than in the other great series of formations. Here they are regarded as congenital—that is, due to some peculiarity in the crystallisation of the rocks, and not to any changes which have happened since they were cooled. For instance, in granite, little bits of mica, hornblende (Fig. 52), and rolled-clay pebbles, will be found imbedded in the once liquid mass—just as the "clay galls" are seen in the middle of a piece of sandstone—and cavities containing beryls, topazes, cairngorms, and other minerals rarely found in the rest of the granite. In trappean rocks there are rarely any concretions in the true meaning of the term—albeit the word is used in no very determinate sense—for the only irregularities which can be fittingly bracketed under this head are the amygdaloidal cavities which, as already mentioned (p. 93), so often contain pebbles and other foreign bodies.

Cone-in-cone.—We have, however, retained for the last a discussion of a "concretional structure," perhaps the most remarkable of any hitherto described. This is the "cone-in-cone" of clay ironstones. As the name suggests, it consists of a series of conical forms often running together into rows and ridges, and consisting of concentric coats. The surfaces of the coats are marked by concentric ridges, giving them a wrinkled appearance so much resembling organic structures as to deceive some persons into the belief that these curious forms may be fossils.* The cones often occur in bands parallel to the stratification of the rock, extending upwards or downwards for a greater or less distance.† It may be added that some coals exhibit an interior structure not widely dissimilar, showing when parted what Mr. Jukes described as "a series of narrow, winding, corrugated ridges and furrows, about one inch wide and deep, fitting closely into each other till separated with some force."

The origin of this cone-in-cone structure is still a theme regarding which various conflicting theories have been formulated; one writer attributing it to concretionary action, the result of a quasi-crystallisation;‡ another to the action of pressure on concretions in the course of formation;§ while a third considers that precipitation meets all the difficulties of the case.‖

* Dawson: "Acadian Geology" (1868), pp. 676, 677.

† Sorby: "Report of the British Association for 1859," p. 124.

‡ Judd: *Quarterly Journal of the Geological Society*, Vol. XXIV., p. 418.

§ Marsh: *Proceedings of the American Association for the Advancement of Science*, 1867; Gümbel: *Zeitschrift der Deutsch. Geolog. Gesellschaft*, Vol. XXXIV.

‖ Daintree: *Quarterly Journal of the Geological Society*, Vol. XXVIII., p. 282.

Mr. John Young, who has made what is by far the most exhaustive study of these curious structures, arrives at a conclusion regarding their origin somewhat different from that of any of his predecessors. He finds nothing in the structure of cone-in-cone to warrant the assumption that it was produced by pressure acting on concretions, or, indeed, by pressure acting on the stratum in any other shape; nor that it is the result of any chemical precipitation from the water in which it was formed; nor of a concretionary or other form of crystallisation in the stratum after the bed was deposited; but he considered it to be due to the upward escape of gases through the sediment, resulting in a mechanical action whilst the deposition of the sediment was going on. It is also a structure which does not affect in the least either the immediately underlying or overlying stratum, and is confined vertically to the thin bed in which it exists, though it may, and does, extend horizontally with the bed over wide tracts of country. The gases which set this mechanical action at work appear to have been generated from the decomposition of organic matter in the deposit. These gases, as they slowly escaped upward through the oozy and plastic mud, "elevated the sediment around the several points of eruption into conical ring-like layers," the last feeble ebullitions being indicated at the upper extremities or bases of the cones by the little conical eminences "which now rise above the regular surface of the bed. With the cessation of the escape of the gases from the underlying sediment the structure ceased to be further extended, although deposition of sediment, apparently of the same mineral composition, still went on in the waters in which the stratum was forming." Thus each ebullition of gas was marked by a new or successive layer of sediment within each cone. The transverse wrinklings seen in the calcareous layers of the cones, appear to have been due to a creeping downward from "the gravitation of the gradually hardening surface of the layer of sediment whilst it was still in a plastic state." Upon these corrugated, calcareous layers there have been successively deposited from the waters in which the stratum was forming, those thin clayey layers which now separate the calcareous ones in all the specimens. Finally, it may be mentioned that, among other interesting observations by Mr. Young, he notes how in all the cones there is a central axis in which all the clayey layers converge to form a dark-coloured tube, filled by the clay, and that through this orifice of the axis the sediment forming the calcareous layers was successively ejected during each ebullition of the gas from below, the action being comparable to that of a miniature geyser.* This theory, though not quite conclusive, seems, in spite of the objections urged against its acceptance, the only one which explains in full accord with known physical laws the chief phenomena presented by cone-in-cone.

Metamorphism.

The reader who has read the preceding chapters must have seen that the rocks composing the earth's crust have undergone many changes since they were first laid down in beds by the action of water, or piled up into hills by the force of volcanoes, or accumulated in the various ways already indicated. They have been ruptured and dislocated, twisted and percolated by mineral-laden springs, and into the cracks which run athwart their beds metals have been introduced. All these alterations might be termed metamorphism.† But the geological phenomena which are grouped under this head are of a more restricted character than those hitherto noted, and refer to the changes which heat in various forms, chemical action and reaction, pressure, and possibly electric and galvanic currents, have exercised on rocks unaltered except by the mechanical violence which has disrupted them in the way described. A brief study of metamorphism ought therefore to explain why chalks have, in various instances, become marbles, and sedimentary rocks been turned into the granitic-looking gneiss, or why slates

* Young: *Transactions of the Geological Society of Glasgow*, Vol. VIII., pp. 1—27.

† Greek *meta* (denoting change), *morphe* (form).

can be split along lines of cleavage different from those with which a study of stratification, or joints, or faults, has already made us acquainted.

Heat.—That heat exercises a metamorphosing influence on the structures it comes in contact with is a matter of familiar knowledge to every one. The prismatic texture assumed by the lining of furnaces after long-continued heat, has long been noticed, while the examination of a brick or a teacup shows how clays are consolidated or fused when they are "baked." The "vitrification" of sand into a glassy material is another peculiar case in point. Where trap or granite dykes have obtruded themselves, the rock on either side is—as we have seen (p. 100)—altered in structure, being as a rule rendered more crystalline than the unaltered mass. The high temperature, however, may be applied not by contact, as in the case mentioned, but by transmission in various ways, such as through the heat of a volcano, or by hot springs, steam, or other vapour, permeating for a long period the strata. Even cold water exercises a certain metamorphic influence on the rocks through which it percolates. It is found in more or less minute quantities in all rocks, even the quartz of granite being full of tiny water vesicles, of which only the furnace can deprive it. Some granites, indeed, contain in their ordinary state a pint and a half in every cubic foot. Chalk is also highly absorbent, some forms of it being able to take up half of their bulk without appearing to be moist. Ordinary sandstones hold nearly a gallon in a cubic foot, and, according to Ansted, in the best building stones belonging to the Sandstone group from four to five pints of water are contained in each cubic foot of the stone. The quantity of water capable of being held by common loose sea-sand amounts to at least two gallons in a cubic foot, while into the layers of sand between the harder rocks so much water is always soaking that the driest seasons do not exhaust these reservoirs. By dissolving out certain chemical constituents in the rock, water must, therefore, exercise some alteration on the beds through which it percolates or in which it stands. This power is, of course, greatly intensified by heat, and this heat we know is added to it in constantly increasing amounts as the water descends towards the interior of the earth. Even at so low a temperature as from 59° to 172° the mineral waters of Plombières, in the Vosges, have in one week produced zeolites—minerals consisting of silicates of lime and magnesia—on the Roman brick pavement over which they flow, while other experiments by Daubrée were even more strikingly in proof as to the remarkable influence which water of a high temperature will exercise on substances seemingly the least easily affected. If to heat pressure be added, the result will be still more marked. Now, when, besides all these factors, the one of almost unlimited length of time has been allowed, the metamorphic action of water must be very great. We have already noticed the action of hot springs in producing the vein-matter of lodes (p. 107).

Dolomitisation.—To the same action may be attributed the metamorphism of some rocks where no other action can be traced, and the conversion of an earthy limestone into dolomite (p. 54), or even into ironstone, according to the substances which the hot water may hold in solution or in suspense. Dolomite * is not necessarily a metamorphic rock, since we know that it may be a chemical precipitate. But very frequently it has been converted from a limestone containing carbonate of magnesia by the simple abstraction of carbonate of lime, or in various other ways by which carbonate of lime might be replaced by carbonate of magnesia. Thus the "dunstone" of the North of England and of Ireland is dolomite produced by the alteration of the carboniferous limestone for a few yards on either side of the joints running through it. However, where, as in the Eastern Alps, dolomite forms great mountain ranges, Dr. Archibald Geikie and other writers are doubtless right in regarding them not as altered ordinary limestone, but in all probability as produced at the beginning "by the action of

* After the French geologist Dolomieu. Chemically, it is a more or less crystallised variety of magnesian limestone.

the magnesian salts of the concentrated waters of inland seas upon organic or inorganic calcareous deposits accumulated previous to concentration, their metamorphism having consisted mainly in the subsequent generation of a crystalline structure analogous to that of the conversion of limestone into marble." In like manner acid vapours and the gases issuing from volcanic cracks must have played some part in altering the structure of rocks, though it must be remembered that it is rarely that the agencies mentioned have acted singly. More frequently they have been in conjunction or in union with the second great order of metamorphic agencies, still to be described.

Pressure.—The metamorphic agencies, discussed with the brevity which our space demands rather than their importance merits, alter not only the physical but the chemical structure of rocks. We now come to a series of agencies which by rearrangement of the molecules of the rock have succeeded in changing the texture mainly by the rearrangement of the materials composing the mass. These consist in pressure, combined, no doubt, with motion, and more or less with the other metamorphic influences just described. Rocks thus altered exhibit a peculiar fissile arrangement which enables them to be split in directions more or less oblique to the plane of stratification or bedding. Such a class of metamorphosed rocks is seen in the clay-slates used for roofing.

Cleavage.—Some sedimentary rocks—rocks in which the lines of bedding are perfectly clear—have cleavage planes more or less transverse to the ones in question. Not only do they, like joints, divide the bed in which they might be supposed to have originated, but they extend often parallel over a wide area, cutting through beds of various geological ages without any regard to the flexures which the beds have undergone (Fig. 61). The dip of the strata affected may be the exact opposite of that of the cleavage, while the strike may be different, or the dip of the plane of bedding and of the cleavage structure may point in the same direction, though the angle of their dip may be different. Various rocks are affected by cleavage, though most of them are of very ancient date; but the ones most familiarly "cleaved" are roofing-slates, the finest grained rocks being thus most markedly affected. In clay-slates the rock splits into the thin laminæ so well known, each plate being perfectly parallel with the one above and below it, and of equal thickness throughout. If it happens that fossils are in the beds affected—as in some sandstones and limestones—the shells or other organic remains are contorted also, showing that the alteration in structure has been undergone since the beds were laid down, and is in no way due to anything connected with its mode of formation. It is clear, after exhausting all possible agencies, that intense compression, with motion of the particles com-

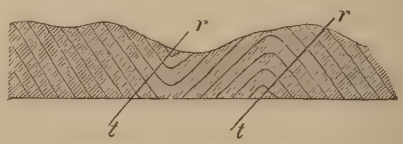


Fig. 61.—CONTORTED STRATA.

(Showing Planes of Cleavage [*r*—*t*] obliquely to the Planes of Bedding or Deposition.)

posing the rock, must have been the agency at work in producing this remarkable structure. In examining thin slices of roofing-slates under the microscope, Dr. Sorby noticed that the granules were on the lines of cleavage flattened lengthways in their direction, so that the pressure which produced this flattening must have been great and applied laterally. In coarser-grained rocks this structure is easily seen, the pebbles of some conglomerates being flattened, so that their largest axis is parallel to the lines of cleavage and oblique to those of deposition, and, as we have seen, any fossils in the cleaved beds take a similar distortion. Professor Tyndall has produced cleavage in clay, white wax, and similar substances, by applying pressure to them, allowing them at the same time to expand in directions transverse to the pressure; while contortion, according to the experiments of Sir James Hall, must have arisen

from lateral pressure acting with some degree of resistance from above and below. Still, though cleavage may thus be produced by the mechanical forces which have been at work in the earth's crust, it is by no means certain that heat has not also been concerned in it, or that this will explain all the phenomena of the particles lengthening their axes in the direction of the cleavage planes.

Cleavage, by its abruptness and frequently high angle, does not impress the scenery of a country to the same extent as the planes of stratification when they crop out in cliffs on one side and slope away on the other. Yet, as Mr. Tate notes, the actual direction of the great ridges is often due to the cause which has produced cleavage, and is not coincident with the strike of the bedding. On the other hand, the great ridges of strata are often cut through by cross-cleavage, so as to give passage to rivers flowing through narrow glens, wide valleys being more characteristic of the streams which have worn themselves beds in rocks unaffected by these divisions. It may be added that in some instances there have been noted secondary cleavage planes cutting across the first, and then when an igneous dyke or vein crosses a bed the line of cleavage runs across it without break, as in the case of a vein of "porphyry," figured by De la Beche,* crossing Devonian slates in Plymouth Sound.

Foliation.†—This has been defined as "a separation into layers of different mineral composition," as distinguished from cleavage, in which there is only "a tendency to split" in a mass of the same composition. It may therefore follow the line of cleavage, or of stratification, or of the false bedding produced by currents, but, like cleavage, it has invariably been produced since the rock was first formed. The "schistose" structure of many of the metamorphic rocks, like gneiss, mica schist, etc., is due to this foliation. What causes these alternating layers or plates of mineralogical structure has still to be discovered. It may be that the electric earth currents have had some share in the matter.

* "Geological Observer," p. 621.

† Latin, *folium*, a leaf.

For convenience' sake this peculiarity of rocks has been bracketed under the head of the force which it is allowable to believe has produced cleavage, and, by some geologists, pressure is considered to have produced foliation also. This, however, is an hypothesis it is not quite easy to accept. It is not difficult to imagine, as has been done, that foliation, if it consisted solely of a change in mechanical structure, could have been effected by mechanical force. But it is hard to realise how the same agency could have resulted in an alteration of the mineral structure of the rock itself. Yet this is what we see in foliation. In reality, cleavage is not always coincident with foliation; while it is not uncommon to find unfoliated limestone and other beds intercalated with strata which have undergone that change. The belief is therefore gaining ground that only rocks containing alumina and magnesia are capable of producing the mica and felspar the layers of which are so characteristic of this form of metamorphosed rocks. Nor does it invariably happen that the cleavage has been produced before the foliation, or that the planes of foliation coincide with those of cleavage; but it may be readily understood that when the cleavage lines were formed before the foliated structure was imparted to the rock, the mica and felspar would, under the metamorphic influences, arrange themselves along these pre-existing divisions.

But, experience teaches us, the foliations are just as often coincident with stratification. In other words, the "folia" are parallel with the planes of bedding. Those who hold by this fact are inclined to attribute foliation to some force which was at work at the time the stratified rocks were deposited. Sir Charles Lyell leaned to this hypothesis, while fully admitting "that the alternate layers of quartz, or of mica and quartz, of felspar, or of mica and felspar, or of carbonate of lime, are more distinct in certain metamorphic rocks than the ingredients composing alternate layers in most sedimentary deposits, so that similar particles must be supposed to have exerted a molecular attraction for each other, and to

have congregated together in layers more distinct in mineral composition than before they were crystallised." Finally, the latest researches on the subject—namely, those of Dr. Sorby—go far to show that cleavage and foliation are essentially different, and that neither is in any way the direct result of stratification, cleavage being "the result of the varying segregation of different minerals controlled by various previously-existing structures," the various appearances which foliation presents depending, according to this distinguished observer, on whether or not the rock had become completely solid or crystalline before it was compressed, or was compressed before it became solid and crystalline. This, however, leaves the question pretty much where we found it: for it does not attempt to explain what the agency was that segregated these layers of mica and felspar from the substance of the rocks to which they now give so characteristic an appearance.

The Metamorphic Rocks.—This term, applying as it does to any rocks which have been altered since they were first laid down or erupted (for some of the igneous rocks are also metamorphosed) in the limited manner described, does not properly define those of any particular geological period. However, what has been long known to systematic writers as the "metamorphic system" comprises the crystalline "schists," such as gneiss, quartzites, mica-schist, and clay slate, which underlie the beds containing fossils, and out of which no traces of animal or plant remains have been disinterred, though, likely enough, they were at one time existing in these rocks. These beds often run into one another, and all alike bear the characteristic of being hardened and crystalline, and, for the most part, cleaved, foliated, and crumpled, after the manner already described. They are also known as azoic, that is, without life; and hypozoic, that is, under the ones containing life, or fossils, which are the remains of organic beings. Most of the Scottish Highlands, Scandinavia, and the Central Alps are regions in which metamorphic rocks prevail, though in these countries the metamorphism is not due simply to the strata having come in contact with vast masses of igneous rocks, in the same way that we have seen rocks altered by coming in contact with trap dykes, or similar masses of eruptive granite. Intrusive rocks of this character do occur, but not in such abundance, and of such magnitude, as to justify us in attributing this "regional metamorphism" to them. In such cases as those of the Scottish Highlands and the Swiss Alps, the newest views tend to attribute their widely extended metamorphism to "the combined effect of great vertical and lateral pressure acting under a high temperature, and in the presence of water or water vapour; such rocks being now exposed at the surface in consequence of the removal of the material which once overlaid them."* (Fig. 62). The chief metamorphic rocks bear out the doctrines advanced in the foregoing pages.

Fig. 62.—STRATA ORIGINALLY HORIZONTAL WHICH HAVE BEEN CONTORTED AND TURNED UP ON END. (*After Ramsay*).

Quartzite is so termed, not that it has any connection with the quartz or the impure rock-crystal found in veins, but simply because the sandstone which it originally was, having had its grains of silica (*i.e.*, sand)

* Browne: "Handbook," p. 447. See also Callaway, in "Science for All," Vol. III., p. 200.

fused and agglutinated, bears a resemblance to the material from which it takes its name.

Slate, as we have seen, is a clayey rock altered and exhibiting cleavage; while *Phyllite* is a glossier form of the same rock, and more metamorphosed than it.

The *Schists* are "foliated rocks splitting up into thin layers of different mineral matter." Thus, *mica schist* is the name applied when mica is predominant, *quartz schist* when quartz is most abundant, *hornblende schist* when hornblende appears, and so forth, throughout a long list of varieties.

Gneiss, again, is a foliated rock consisting of quartz, felspar, and mica, arranged in the layers characteristic of this description of metamorphosed beds, and comprising a number of forms, some of which are hard to distinguish from granites, and, indeed, are by some lithologists classed among them. The metamorphism of limestone and chalk we have already noticed (p. 97), the marbles and dolomites being among the most familiar results of these alterations, while anthracite and graphite—the "black-lead" of the pencil-maker (though in reality it is simply carbon)—result from the metamorphism of coal, though the exact conditions under which they have been altered are still open to discussion.

Metamorphosed Igneous Rocks.—Among the metamorphosed igneous rocks we find several varieties of granite, though for the present we must be extremely careful in accepting the supposed "facts" which have been adduced in support of the theory that some of the granites are really only extremely metamorphosed varieties of gneiss. However, there cannot be any doubt that some true granites have been metamorphosed. Among them may be classed the one in which the mica and felspar are more or less replaced by tourmaline, as in the luxullianite of Cornwall (p. 91), or in the Zwitter rock of the Germans, in which chlorite, tin ore, and arsenical pyrites are added to the ordinary constituents of granite; or in *greissen*, where the felspar mostly disappears, and lithia mica takes the place of the ordinary form. Among the dolerites Mr. Jukes-Browne classes various gabbros, and diabase, as metamorphosed igneous rocks, and mentions the white trap of the carboniferous rocks of Staffordshire and Central Scotland as basalt, much decomposed and assuming an earthy texture and a pale cream-coloured tint. In like manner, the true serpentines, for the term has been very vaguely applied—such as those of which the Lizard Serpentine in Cornwall is the type—(variegated, compact, massive rocks with glittering crystals of a variety of the mineral called enstatite) may be regarded as altered igneous rocks of the Peridotite group. In Forfarshire and Kincardineshire Serpentine traverses the old Red Sandstone in the shape of dykes. But when it is intercalated among schistose rocks and altered limestones, as in the West of Scotland, it is probably a dolomite still further metamorphosed, though this is a question which it is unnecessary to discuss, enough having already been said regarding metamorphism so far as it concerns the physical geographer.

Yet to show the difficulty of the subject we may add that Sir William Dawson, who, by his long-continued researches has acquired a prescriptive right to speak positively, is quite convinced that "nothing can be more certain" than that the Laurentian gneisses of Canada—in which is found the *Eozoon canadense*, a foraminifer so obscure that by several geologists it is regarded not as a fossil, but as a mere crystallisation—are not ordinary sediments metamorphosed. "They are rocks peculiar in their origin, and not paralleled, unless exceptionally, in later times." Nevertheless, it is undeniable that they have been subjected to very important changes, more especially as to crystallisation,* the state of combination of their ingredients, and the development of disseminated minerals;† and while this may in part be attributed to the mechanical pressure to which they have been subjected — this pressure

* Or what Bonney calls *Metastasis*.

† The second and third of these changes come under the head of what has been called *Metacrasis*. *Methylosis*, or change of substance, is altogether exceptional. We see it in cases where volatile matter has been expelled, as in the change of hæmatite into magnetite iron ore, or of bituminous coal into anthracite.

developing heat such as that which might have been at work in the wide region metamorphosed in the Highlands of Scotland—it requires also the action of hydrothermic, or hot-water agencies. These remarks, however, apply mainly to the Lower Laurentian gneisses. In the Middle and Upper Laurentian we have metamorphic rocks—*e.g.*, quartzite and limestone — which must originally have been ordinary aqueous rocks. Still more in the succeeding Huronian and its associated series of beds, and in the even more recent Lower Palæozoic, local metamorphic change has been undergone by rocks quite similar to those which in their unaltered state constitute regular sedimentary deposits. That these old gneisses were deposited not only in what is now the bed of the Atlantic, but also on the great continental areas of America and Europe, is evident to any one who considers the wide extent of these rocks, as mapped by Professor Hull. *

Geological Maps.

A few words on this subject are necessary before we begin a description of volcanoes, and the other agents which have been at work in moulding the earth in the past, just as they are engaged in re-arranging the materials at present. A map is simply a chart in colours or in conventional shading, representing the different kinds of rocks which make their appearance on the surface. To draw such a diagram it is, of course, necessary, in the first place, to have for the ground-plan an accurate map of the country to be surveyed. In Europe and India, and in some of the more settled parts of the colonies and the United States, this is practicable. But in wilder countries, such maps not being forthcoming, the geological one that is drawn on the basis of those accessible is necessarily inaccurate, and therefore, though useful enough for the geographer's purposes, is of less value to the miner. The limits of each formation must be marked out; the dip, strike, syncline, anticline, veins, etc., must be indicated by certain symbols, on the nature of which geologists are agreed; while the character of the rocks themselves is usually indicated by colours. But as it is comparatively rare for any rock to be exposed for any distance, or over any great space, it is necessary to arrive at the data regarding its area by watching the places where it outcrops, or where it is exposed on the banks of rivers, in quarries, or in cuttings of any sort. Thus a fair inference may be arrived at regarding the spots covered by vegetation, or by the superficial accumulations of soil; though not unfrequently—either by imperfect observation, or by hasty conclusions—important facts are left unnoticed by surveyors who have in this manner to piece a map together from fragments of this kind. But we should obtain a very rude acquaintance with the geology of any country if we remained content with a mere flat map of the region examined. To ascertain how the beds lie, what is below them, how they are tilted or contorted, what are their strike, faults, and a dozen similar points, we must make an ideal section or cutting across the country. This can sometimes be done with considerable ease by following the bed of a deep-lying stream. In most cases, however, the section (like the flat map) must be pieced together, some places being better exposed than others; while at other spots, where the soil hides the rock, a skilful diagnosis from the bits cropping out will enable us to draw such a section for long distances or to considerable depths. Quarries, railway cuttings, wells, coal pits, river channels, and sea cliffs, afford the best data for this study. The result we see in such sections as those figured on pp. 73, 74, 75, 78, 80, 81, or in Fig. 63.

It is, however, easy to see that the same representation on a geological map of a number of strata will have to be differently explained, according to whether these beds be, for example, anticlinal or synclinal. In the first case (Fig. 63A), 1 in the map would indicate the oldest rock which formed the foundation of an island figured, and around which

* "Presidential Address to the British Association at Birmingham," 1886.

the younger formations (2, 3) have settled down like a cloak or a belt, in much the same manner as the lines of equal depth surround the coast-line of a sea chart. This comparison might also be carried farther, in so far that the

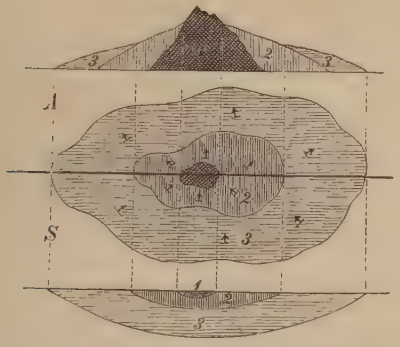


Fig. 63.—DIAGRAM ILLUSTRATING THE FORMATION OF A GEOLOGICAL MAP.

outlines of 1 and 2 were really, during the settlement of the next formation, actually coast-lines, if we suppose an unchanged surface of the sea, and that the land has, step by step, risen during the accumulation of these formations. In the second case, when the beds are synclinal (Fig. 63s), 1 in the map will represent the youngest formations, and appear to be the last material filled into a water basin, originally much larger, in which the formations 2 and 3 have been accumulated at an earlier period. It thus becomes clear that the uppermost and youngest formation (1) has the smallest horizontal expanse of all, and that each one following—though appearing perhaps on the surface only as a more or less narrow ribbon—takes up a larger cubic measure, as it stretches from side to side, under the one above it.

A geological section enables us not only to ascertain the superposition and lay of rocks, but, if it be drawn to scale, demonstrates that the breadth of a mountain's base is always greater than its height. Moreover, as Mr. Ruskin has shown very clearly, slopes of more than 30° in angle are by no means frequent, and declivities of more than 40° always consist of naked rock, while actual precipices are much rarer than is usually imagined if one may gather anything from the rhapsodies of Alpine tourists.*

The ascent to the summit of a mountain being foreshortened, appears abridged to the eye surveying it from the base, and consequently the steepness of the mountain from the bottom to the foot is ordinarily much exaggerated by the imagination. Thus, the Alps rise from the plain at an angle of from 3° to 4°, and the Pyrenees are not much steeper. With an ascent of 5° a carriage road becomes difficult; when the angle rises to 7° it is impracticable. A man climbs rather than walks up an ascent of 30°. Etna, for example, though standing on a base of thirty miles, and with a slope of only 10°, cannot be ascended in one day. The sides of a volcanic cone often make with the horizon an angle of 30° or more; but these form exceptions to the general rule holding in great ranges. Limestone ranges often spring abruptly from low ground, and with precipices "spread out above into elevated plains, so that their altitude, compared with the area covered by them, is not usually great." Indeed, so gradual is the general ascent of mountains, that after tramping for ten miles, it is rare for the climber to find that he has "made" more than one-tenth of that distance into the upper air.†

* "Modern Painters," Vol. IV., p. 183; and Archi Geikie: "Text-Book of Geology," pp. 40, 41, where some of Mr. Ruskin's illustrative cuts are reproduced.

† Cooley: "Physical Geography," pp. 349, 350.

CHAPTER VI.

Volcanoes: their Geographical Distribution and Character.

Uniformitarianism the Basis of Geological Philosophy—The Geological Agencies at present in Force have been acting from the Beginning—Instances: Volcanoes—Their Nature—Appearance of a Volcano—Distribution of Volcanoes—Various Volcanic Bands—Ruined Volcanoes—Domed Volcanoes—Craters—Crater Lakes—Examples of some from Europe, India, and America.

In the preceding chapter we have seen that the beds of rock, or the masses which are not arranged in layers, present certain characteristics, and that these characteristics can with few and very minor exceptions be explained by the action of forces still in operation. What is more, there is no reason for believing, from what we see in the earth's crust, that these agencies have ever been at rest, or that since first we obtain glimpses of the story of creation any new laws have come into operation. In brief, the modern doctrine of *uniformitarianism*—that is, that every phenomenon we have noticed in the rocks, or may still have to study, is due to the uniform play of those "geological forces" which the Creator has permitted to act throughout unnumbered ages—lies at the foundation of the science. In themselves these forces may sometimes appear slight, but their combined action going on continuously has, as we shall see, been amply sufficient to explain the eruption of the igneous rocks, the wearing down and deposition of the stratified ones, their disruption, contortion, and metamorphism, and the successive birth and disappearance of the plants and animals which were contemporary with them, and are now more or less entombed in these rocks in the shape of fossils. The volcanoes are still, as they always were, vomiting forth ashes, lava, and other exuviæ of the underground world; the strata are still being so continually broken and faulted by earthquakes, that there is probably no part of the world which is not, or has not been, within the limited period of which history takes cognisance, subject to one or more shocks. The sea and its waves, the rivers, the glaciers, and the weather, are still, as of old, wearing away the rocks, while the continents are rising and sinking in our time, as they seem to have risen and sunk in the far-away days which we know as geological times. In reality, all times are geological. The corals are rearing islands on the shoulders of ancient volcanoes; the icebergs are bearing rocks far from the spot where they were detached as moraines from the sides of the valley through which the glacier ground; the glacier streams, laden with mud formed by the detritus of the rocks over which this vast file moved, are filling up the Arctic fjords in the same way that their more southern predecessors of the Glacial periods did, and very likely, under the great "inland ice" of Greenland—which is the exact counterpart of the ice-cap of Scotland in the geological period referred to—is forming that boulder clay which has so long puzzled those geologists who attempted to account for it without reference to causes still in operation.

The ice-grooved rocks of Norway and of Great Britain, and such *roches moutonnées* as that which every year a thousand tourists see in the stone near the first bridge in Borrowdale, must be studied not by drawing on hypothetical causes, but by examining the same sort of scratches and ice-worn rocks in the Arctic regions, in Switzerland, or in some other part of the world where Nature still acts through the same agents as those which left these memoranda of their operations behind them. It is, therefore, necessary to study what has been termed geological dynamics—volcanoes, earthquakes, glaciers, rivers, and the like—in order that we may understand

the causes of what we have described, and shall still have occasion to study. Here, accordingly, geology meets geography. In the next few chapters the one will be inseparable from the other, for the present explains the past, and the facts deduced from the past prove how long the so-called modern agencies have been at work.

The Vulcanism of the Earth.

Among the most notable, though perhaps not the most powerful, of the agencies which have always been at work reassorting the materials of the earth's crust, and bringing to the surface matter which lies beneath it, are the volcano and the earthquake, two forces intimately united, and which conjointly have been designated *vulcanism.** Alex. von Humboldt defined this as a reaction of the internal core of the earth against the surface, this reaction being due to earthquakes and the causes which produced them. The exact observations which have been made enable us, if not to predict or to guard against these disturbances, to deduce some laws regarding their occurrence. We know, for example, that when a volcanic eruption occurs it will run a certain course, and—after discharging its steam, scoriæ, and lava—will cease, it may be for a short period, or for ages. We can also sometimes predict from certain signs that an eruption is on the point of occurring, though no deduction has yet been formulated which enables us to say that at a given hour, or day, or month, an earthquake may be looked for; but no doubt it has been attempted to show that in certain seasons and in certain weathers, these tremors of the earth's crust are more frequent than at other times or under different atmospheric conditions.

Appearance of a Volcano.—This is so marked that almost every one is familiar with it from pictures. A volcano is a mountain wherein periodical eruptions occur. These eruptions take place for the most part through an opening in the summit known as the *crater*, a word literally meaning *cup*; the molten matter, ashes, and other discharged matter rising from the interior reservoir through a pipe or chimney, which extends through the one, which cone, again, is formed of the accumulation of ashes, lava, and other *débris* vomited during ages, and rests on the original rocks through which the volcanic discharge first took place (Figs. 55, 64, 65, 68).

These eruptions appear to occur periodically. Periods elapse during which no discharge takes place. The volcano is then "dormant." Vegetation fills up the crater, crops are gathered on its sides and at its base, and the volcano appears to be "extinct," like those of Auvergne in France (Fig. 64), and the Eifel, between the Rhine and the Moselle, in Germany. But suddenly some rumbling noises are heard. Explosions occur, water vapour and gases are ejected, and the volcano is said to be steaming. The next stage is when the burning mountain is said to "smoke" and "spit fire," though considerable intervals may elapse between these stages and the great eruption of ashes, lava, and other materials which follows.

These periods are long or short, the interval between two eruptions being great, and then the lapse between those which follow being comparatively brief and regular. Etna, for example, which is 10,867 feet high,† makes pauses of from ten to twelve years, during which time no eruption takes place. Stromboli, in the Lipari Islands of the Mediterranean (the cone of which is 3,022 feet high), has for the last 2,000 years been in constant activity, though there are Quaternary formations forming in places where at one time slag and ashes were ejected. It is, therefore, rather exceptional; for Sioa in the Moluccas, Tofua in the Friendly Islands, and Sangay and Cotopaxi in the Andes (Fig. 65), are among the few volcanoes of which the same can be said. Yet the explosions occur with such rhythmical regularity of from three to ten minutes and

* Of course, from Vulcan, the God of Fire.

† According to the new map of the Stato Maggiore (3,312·61 mètres). Smythe determined it to be 10,874 feet; while Herschel, thirteen years later, though unacquainted with his predecessor's work, estimated it at only eighteen inches less.

upwards, that visitors can approach the crater without danger, stones ejected from it almost all falling into the opening again. Vulcano, in the same group, the crater of which is constantly smoking, is said during some of its more recent eruptions to have displayed a periodicity of from twenty to thirty minutes; though, as a rule, it does not display the

fifty years later, an earthquake occurred which severely damaged Herculaneum and Pompeii. Others followed at intervals, until the 24th of August, A.D. 79, when the first recorded eruption occurred, the violence of which was such that the country was desolated for miles around, and Pompeii, Herculaneum, Stabiæ, and other villages in the vicinity, were

Fig. 64.—PUY DE LAS SOLAS AND PUY DE LA VACHE (EXTINCT VOLCANOES IN THE PUY DE DÔME CHAIN), AUVERGNE.

regularity of Stromboli, the explosions of which can be counted on almost like pulsations. Vesuvius—the height of which varies, according to the different eruptions, from 3,900 feet in 1845 to 4,250 in 1886—was silent for at least 2,000 years. In the reign of Cæsar Augustus it was covered with beautiful meadows, the summit being the only portion of it altogether sterile. But so little danger was apprehended from an outbreak, that the crater was the refuge of the gladiator Spartacus and his rebel army. About

overwhelmed by the showers of ashes and the vast streams of volcanic mud which poured down the sides of the mountain. Up to the year 1500, nine eruptions are on record. Since that period it has often been quiet for long intervals; then for a period it has been almost uninterruptedly active. Of late, the pauses have rarely exceeded three to four years, and during these outbreaks the eruptions display a periodicity in their convulsive efforts of much the same character as those of Etna. Kilauea, in the

Sandwich Islands, vomits forth lava at intervals of from eight to nine years, this interval being required to fill up the crater with the molten matter which at the end of that period overflows. Hualalai, after three outbursts early in the present century, has been dormant since 1811. Mauna Kea seems to have reposed for centuries, and the natives have no traditions of Haleakala, on the Island of Maui, having ever been active, while Mauna Loa is apt to discharge its great lava rivers at uncertain intervals. But on the other islands the volcanoes have long been extinct, and already are being worn away by the elements. In Oaha, however, Dutton noticed recent cinder cones which appear to indicate a resumption of volcanic activity after a period of very long quiet, though, relatively speaking, the results so produced were not great, and the activity was diffuse, and comparatively feeble. Similar evidences of volcanic eruptions, long after the vent was believed to be extinct, have been discovered in some of the more recent volcanic fields of the Rocky Mountain regions.

Fig. 65.—COTOPAXI.

Distribution of Volcanoes. — Alexander von Humboldt has carefully catalogued the number of active volcanoes which appear to have been in eruption during historical periods. From the results of this inquiry it would appear that out of 407 active volcanoes only 225 can be counted as having been in

eruption since the beginning of the present century. His table is as follows :—

	Total.	Active.	Total.	Active.
1. Europe	7	4		
2. Islands of the Atlantic Ocean	14	8		
3. Africa	3	1		
4. Asia :—				
(*a*) Western and Central portion ...	11	6	25	15
(*b*) Peninsula of Kamtchatka	14	9		
5. East Asiatic Islands ...	69	54		
6. South Asiatic Islands	120	56		
7. Indian Ocean	9	5		
8. South Sea	40	26		
9. America :—				
(*a*) South America—				
(*α*) Chili	24	13	115	53
(*β*) Peru and Bolivia	14	3		
(*γ*) Ecuador and New Granada	18	10		
(*b*) Central America...	29	18		
(*c*) Mexico, south of the Rio Gila ...	6	4		
(*d*) North-West America — North of the Gila	24	5		
10. The West Indies ...	5	3		
	407	225		

The newer tables of Dr. Fuchs give 672 volcanoes, of which 270 are now active (80 in America, 24 in Asia, and 20 in Africa, or its islands, only one being on the *Continent* of Europe), the difference in the two estimates being due to the different opinions held regarding what constitutes an active, a dormant, or an extinct volcano.

In Java, for example, there may have been counted 109 volcanoes, of which 28 are now in activity. In the Isthmus of Auckland, in New Zealand, in a space of 128 square miles there are as many as 63 small, scarcely extinct or active volcanoes, of from about 196 to 990 feet in height, each of which possesses its own distinct crater and lava system. In the Phlegræan fields, near Naples, Breislack has counted 27 craters. In Auvergne, in Velay, and Vivarais, in France, and on the banks of the Rhine, in the vicinity of the Laacher See,* and in the Eifel, we also see some groups of extinct volcanoes. These last-named were active in the Tertiary and Diluvial periods, and we are able to recognise the invariably circular form of the craters, and the lava streams, the ashes and slag of which are still visible in their immediate vicinity.

A glance at the distribution of volcanoes shows that they are unequally scattered over the whole world. The old continents—Europe, Asia, and Africa, and their islands—are thickly studded over with extinct or active volcanoes, though none are known to exist in Australia. But the great volcanic basin of the earth appears to be in the bed of the Pacific Ocean. From Mount St. Elias in the north, to Mount Erebus and Terror in the south, a range of volcanoes can be traced in the ocean, so that we may say that the earth is from sea to sea girt with a volcanic belt. This zone of fire comprises the west coast of North and South America, from the Aleutian Islands to the Peninsula of Kamtchatka, and extends across the East Indian Islands to the Gulf of Bengal—each of these groups of islands being full of volcanic vents, and possessing an aspect peculiar to itself. We may further notice in the Pacific Ocean a number of surfaces which occasionally exhibit the same phenomenon as on the continents. But, naturally, we know less of this water-covered portion of the earth's surface, though we can imagine that if the terrestrial influences are not favourable for the occurrence of many volcanoes, the chemical and mechanical operations on which they depend are not suspended.

We see, in fact, that the volcanic action is so distributed that it is possible to refer the vents to one central part from which all of them diverge. The first and greatest of these lines stretches, we have seen, from near the Arctic Circle to the Bay of Bengal, comprising the Aleutian Islands, Kamtchatka, the Kuriles, Japan, the Philippines, and the Malay Islands. Its greatest focus of activity

* This lake is in the crater of an old volcano.

seems to lie in the region between the islands of Borneo and New Guinea, which has often been the scene of most violent eruptions and earthquakes. From this centre, one line radiates through the Philippine Islands, a second in an opposite direction through New Britain, the Solomon Islands, the New Hebrides, New Zealand, and South Victoria, where Mount Erebus belches fire over the Antarctic snows, while Java and Sumatra form the principal land surfaces in the line of the third branch.

A second band of volcanic action extends along the west coast of North and South America.

A third traverses the Atlantic, from Greenland and Bear Island—where volcanic rocks occur, though no active volcanoes—by way of Jan Mayen, on which is a volcanic peak (the Esk) still occasionally in eruption, Iceland, where Hecla is the principal active vent, the Azores, the Canaries, the Cape Verde Islands, St. Paul, Ascension, St. Helena, Trinidad, and Tristan da Cunha—on all of which there are either volcanoes in a state of activity, or which may be regarded as dormant or extinct. In Great Britain and the opposite portion of the Continent there are no active volcanoes. Yet Skye and Mull must during the Tertiary period have been the scene of violent volcanic disturbance, for though worn down by the action of the weather and other denuding agents, it is still easy to trace in these islands the "basal wrecks" of the old cones (p. 102). In many other regions, during different geological periods, volcanoes must have existed. Indeed, wherever we find volcanic rocks there the volcanic vent must have been present. From the volcanic band just described the volcanoes of the Mediterranean, including Etna, Vesuvius, Stromboli, Santorin, &c., are a branch.

Thus it appears that the first of the volcanic lines named stretches for nearly 10,000 miles, and, with its branches, contains 150 active volcanoes; the second includes in its range of 8,000 miles about 100 active vents, and the third contains about 50 active volcanoes, scattered over a length of nearly 1,000 miles.

Finally, a fourth band has been traced along the eastern coast of Africa, where Mauritius, Bourbon, Rodrigues, and the Red Sea vents form the most marked features in the line noted.

Again, if we study the map on which these volcanic openings are portrayed, we may classify them as (1), *Central Volcanoes* (comprising isolated volcanoes and volcanic groups), which would include the volcanoes of Iceland with those of the Canaries and the Azores, the Cape Verde Islands, the Sandwich Islands, the Galapagos, etc.; and (2), the *Chained Volcanoes*, which are uniformly disposed in single lines. Thus Vesuvius indicates the southern point of a line about 200 miles long, stretching from the west side of the Apennines in a north-westerly to a south-easterly direction, and along this volcanic line it is not too much to infer that volcanic force is still existent, and may at any time display itself. Examples of chained volcanoes may also be seen in Sumatra and Java, the volcanic series of the Moluccas and Philippines, the three-fold volcanic lines of the Peninsula of Kamtchatka (where there are yet active volcanoes with a mean height of 15,000 feet), and the volcanic chain of the Kurile and Aleutian Islands, which contains 36 volcanoes. Still more important is the great volcanic line of 2,800 miles in length, which runs along the western coast of South America, with volcanic vents in Chili, Bolivia, and Ecuador. In Central and North America it is very manifest. In Guatemala the vast rents which often traverse the plains for miles, tell of past earthquakes, and the ancient capital of the State is situated between the Volcan de Agua and the Volcan de Fuego, the latter still occasionally active. The Yzalco Volcano, in San Salvador, is also now and then in eruption, and Nicaragua is traversed in its entire length by a remarkable volcanic chain of isolated cones, several of which are active, or at least only quiescent, the tropical vegetation at their base being little more than twenty years ago —as the writer can testify—covered with the ashes which fell during an eruption of these great burning mountains. In Mexico

earthquakes are common, and Jurillo, in 1759, was in eruption. Popocatepetl emits smoke, and within historic times has been in activity. Orizaba has been quiet for more than three centuries, and though Colima is still often active on a small scale, Tuxtla has shown no sign since 1793, while Jorullo, though it may at any moment vomit forth fire, is at present exhibiting few symptoms of renewing its wonted energy, and the district in its vicinity is again becoming covered with vegetation.

In the western United States there are several more or less active, and a number of extinct volcanoes, the truncated cones of which form so striking a feature of the Cascade Range and its continuations from Alaska southward. Mount Baker, in Washington Territory, as the residents of Victoria know well, is often smoking and vomiting fire, and the Indians have traditions of Mount Hood and other peaks having been in violent eruption within the memory of man. Their summits still display all the signs of vulcanism—hot ground and springs, steaming spots and ashes, while lava is to be seen in the country at their base, and washed up among the gravels of the streams flowing out of their snows. Between the Cascades and Sierras and the Rocky Mountains is a markedly volcanic region. The "lava beds" cover a great portion of the country in the vicinity of Fort Hall. Boiling springs are plentiful both here and in British Columbia, where there are no active volcanoes, though here, in common with the entire Pacific coast, earthquakes of a mild character are frequent. But in Alaska—or, as some recent astronomical observations would indicate, actually over the British Columbian border—Mount St. Elias has been occasionally in eruption,* and off the coast submarine volcanoes connected with the group in the neighbouring Aleutian islands, or on the other side of Behring Strait, every now and again give evidence of their activity. In brief, there are few breaks in the volcanic chain which extends from the Arctic to the Antarctic Oceans.

* Seton Karr in *Kosmos* (San Francisco), Vol. I., pp. 3-6, and *Proceedings of the Royal Geographical Society*, March 14th, 1887.

Ferdinand von Richthofen, after a study of the facts ascertained, has arrived at the following conclusions regarding volcanoes and their relationship to the geological structure of a country: (1), Volcanic action—that is, earthquakes, as well as the more outward manifestations of the underground movements—is most marked in those regions where the continents turn their points towards each other, and are either already joined together, or, by a slight elevation of the land out of the sea, are gradually becoming so (Central America, Alaska, Kamtchatka, the East India Islands and Australasia, the Turkish Peninsula and Asia Minor); (2), That volcanoes follow the abrupt margin of continents (Western line of the Andes and Cordillera, the Philippines on to Liu-Kiu, Japan, and the Kuriles, which may be regarded as dissevered portions of a former continental land mass); (3), That they keep near either the present sea-coast or the sea-coast of the Tertiary period, albeit volcanoes may burst through rocks of every age. In Auvergne, for example, they have pierced the granitic and metamorphic rocks. In the Eifel, Devonian and other old beds have been penetrated; in Italy, Etna and Vesuvius have erupted through the newest strata; while in western North America the vast lavas and tufas of Nevada, Utah, Wyoming, Idaho, Washington, and Oregon, are for the most part overlying Tertiary and post-Tertiary rocks. (4) Lastly, an exception to this rule is afforded by those evidences of volcanic action found in some few plateaux, which for long periods have had no outlet for their water-courses to the sea—for example, the "great basin" between the Sierra Nevada and the Rocky Mountains just mentioned.

Outward Form and Size of Volcanoes.

The mode in which a volcanic cone is usually formed — namely, by the *débris* vomited out of the crater on the top falling down the sides—renders it for the most part of a very uniform shape, and enables the lava streams to flow down its sides into the lower lands after a fashion much the same in every case. For a like reason,

the dimensions of cones are easily examined. The angle which the slope describes to the horizon varies from 3° to 40°, the shape of most of them being very slender. The crater is produced by the same force which ejects the products of eruption. Once it is formed in the shape of an opening in the rocks through which the pent-up material is ejected, it is kept open by the same agencies.

The Cone. — But, meantime, the *débris* gradually accumulating all around it, the cone grows like a molehill on a large scale, while the original crater lengthens, until it is continued downward through the cone in the form of a pipe, or chimney, which at one extremity communicates with the interior of the globe, and at the other is the vent at the top, through which the material passing through it during an eruption finds its way into the air and down the sloping sides of the cone. In this way a cone may be of a greater or less extent, its height depending not only on the amount of material ejected, but on the constancy with which the eruption has been continued, the nature of the *débris* vomited out, and the fact that the volcano has not, during some of its violent moods, formed fresh craters, either on its side or at a little distance, as it not unfrequently does. Nor must we omit to note that sometimes a lofty peak is suddenly truncated during a violent eruption by the volcanic force blowing off the top of it, and thus (p. 120) the fresh eruption, instead of adding to its height, actually diminishes the altitude of the cone.

Some of the South American volcanoes attain the maximum elevation of their order. Thus, Chimborazo is 20,703 feet high; Cotopaxi, the loftiest active volcano in the world, 19,498 feet; and Sahama, 22,350 feet, all of these mountains being in the Andes. Mount St. Elias is 14,970 feet,* Mount Rainier 14,444 feet, Mount Baker 10,760 feet, and Popocatepetl 17,717 feet. Mount Erebus, in the Antarctic regions, is 12,400 feet. In the Old World we have Kliutchevsk, in Kamtchatka, 15,825 feet; the Great Ararat, 16,431 feet; the Peak of Teneriffe, 12,182 feet; Vesuvius, 4,250 feet; Etna, 10,867 feet; and Hecla, 4,532 feet. Some volcanoes barely rise more than a hundred feet above the surface of the soil. Among these diminutive members of a lordly race, are Kosima, in Japan, 745 feet high; and Mandana, in the Santa Cruz or Queen Charlotte Islands of the Western Pacific, which is 213 feet in height.

The Crater.—The crater of a volcano is merely the opening through which the erupted matter finds an outlet, and through its downward continuation serves, as we have seen, to unite the outer world with the pyrosphere or internal volcanic forces, of which the volcanic discharge is the external manifestation. The dimensions of craters vary much. Estimates have been made which prove that in some of them the mouth is over three statute miles in its greatest diameter. The crater of Vesuvius is about 2,034 feet; that of Stromboli, 2,100; that of Etna about 2,300; and that of Popocatepetl, in Mexico, 5,578; while the crater, or, as Captain Dutton insists on calling it, the "caldera," of Kilauea, in Hawaii, attains the enormous diameter of 12,795 feet. But in reality this is a lava lake, rather than an ordinary crater or blow-hole, the usual orifice through which lava and other volcanic matter emanate. All the accessories of Kilauea are different from those associated with normal craters. Counterparts of this caldera are not common. The Val del Bove in Etna appears to be homologous to it; and in the Sandwich Islands the exact counterpart of Kilauea is the great pit on the summit of Mauna Loa, named Mokuaweoweo. The vastly larger depression on the summit of Haleakala, though differing much in form, may also be regarded as identical. Numerous small crater-shaped depressions are found in many parts of Hawaii, which also seem to be of much the same nature, though some of them are only a few hundred feet in diameter, and none of them exhibit any signs of

* According to the Admiralty Chart (No. 2,172); Tebenhoff makes it 16,938 feet; Grewingk, 16,754 feet; the Russian chart of 1848, 17,854 feet; D'Agelet, 12,672 feet; and Davidson, "between 16,700 feet and 17 000 feet;" while Schwatka's expedition of 1886 indicates its elevation at "between 19,000 and 20,000 feet, with a probable error of 1,500 feet."

recent activity. Their origin seems to be due to "the dropping of a block of the mountain crust which once covered a reservoir of lava, this reservoir being tapped and drained by eruptions occurring at much lower levels." Hence, in Captain Dutton's opinion, when people speak of Haleakala as "the greatest

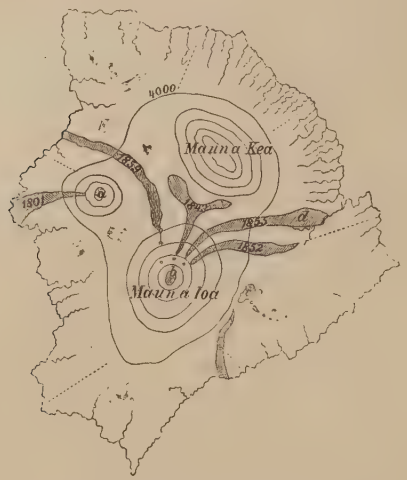


Fig. 66.—THE ISLAND OF HAWAII, IN THE HAWAIIAN OR SANDWICH GROUP.

Showing the different craters and the lava streams of various eruptions. *a*, Hualalai, *b*, Mokuaweoweo, *c*, Kilauea—craters; *d*, lava streams. The contour lines show difference of 2,000 feet in height.

crater in the world," they give rise to endless misconceptions, for it is not a crater at all, and, except for the examples cited, stands by itself* (Fig. 66).

The discharges of lava that flow down the 13,900 feet, due almost entirely to the gradual overlaying of one lava discharge by another, lava being the main matter ejected by them. These mountains differ from the ordinary conical volcanoes in being flat and wide-topped like a concave shield. To an elevation of from 4,200 to 4,600 feet, the slope rises almost imperceptibly from an angle of 1° to 5°, when the incline becomes somewhat sharper, but still remains under 15°. Higher up, the mountain again becomes flat, so that at a distance the summit appears convex, and the whole volcano in shape like a flat-roofed house. The calderas, or lava lakes, of these mountains are, as we have seen, of enormous size, that of Mauna Loa being 12,140 feet in diameter, though it has in addition a side crater of a remarkable character; while Kilauea measures in its circumference more than 7½ English statute miles (Fig. 67). In some of the large volcanic cones, such as that of Etna, or the Peak of the Island of Pico, in the Azores (7,613 feet), there is not only the main cone, which forms a continuous mountain, but a number of smaller parasitical ones arranged around them. Each of these may give rise to its own lava stream, and throw out its own special shower of ashes. In Etna as many as 700 of them—little and big—have been counted.

Ribbed Volcanoes.—In some of the very regular volcanic cones the sides present a valley- and ridge-like appearance, formed by streams of lava radiating from the crater to the foot of the mountain, like so many huge

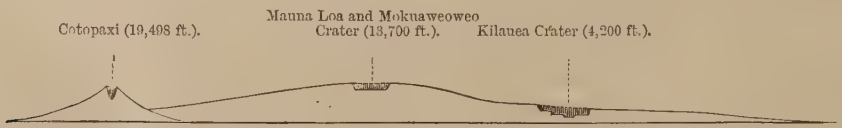


Fig. 67.—DIAGRAM EXHIBITING THE PROFILE OF CONICAL AND FLAT-TOPPED VOLCANOES.

side of volcanoes form, to a large extent, the materials to which they owe the height they have attained. Mauna Loa, for example, to go no farther than the Sandwich or Hawaiian Islands, is 13,700 feet high, and Mauna Kea

* Dutton: "Hawaiian Volcanoes."—*Report of the United States Geological Survey*, 1882—3, p. 105.

ribs. These appearances are due to the erosive action of water, which has flowed down from the summit, which, while it has washed away the softer ashes and other *débris*, has left the harder lava ribs untouched. Such phenomena are exhibited, among other places, in the Gunung Sumbing of Java, in Cotopaxi

in the Andes, in the Hawaiian cones, in most of the Cascade Mountains of North-west America, and in Mount Egmont in New Zealand (Fig. 68). The streams of water flowing from a height descend, in their course, in ravines, which have a definite relation to the axis of the summit crater, for this is the central point from which all of these streams course.

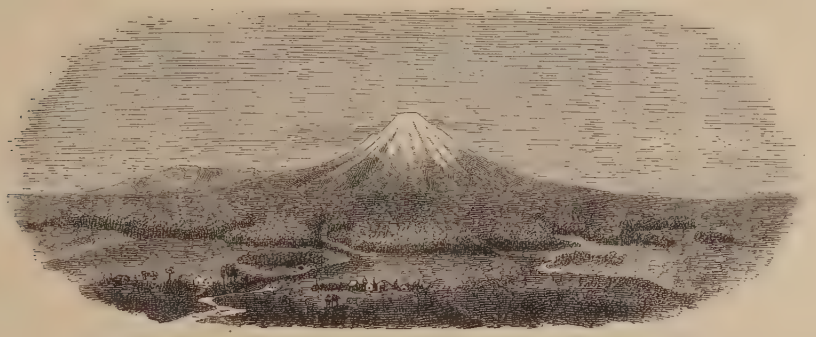


Fig. 68.—MOUNT EGMONT, OR TARANAKI, IN THE NORTHERN ISLAND OF NEW ZEALAND.

The crater is, however, not always so regular or sharply defined as on its first formation. Soon the process of erosion by the elements begins to work, breaking down its sides, so that in time it will appear like a huge kettle

Fig. 69.—THE ISLAND OF PALMA, IN THE CANARIES.

a, *b*, *c*, Caldera; *e—f*, Barranco.

on the summit, with valleys diverging from it on every side. The Island of Palma, in the Canaries (Fig. 69), is an excellent example in which had its origin from the falling in of the side crater of the volcano. (*See* also Plate V.)

point. At a height of 6,562 feet we come to the broken-down crater, or caldera—a kettle-shaped valley surrounded by high walls,—and radiating from it are a number of ravines known as *barrancos*. These names are sufficiently expressive to be applied to other mountains showing similar conditions, as, for example, in the Val del Bove, in Etna (p. 125),

Ruined Volcanoes.—This leads us to remark that every volcanic cone that has long been exposed to the action of the weather exhibits evidences of that erosion and denudation which wind and rains and the other aërial agents are constantly producing. Such erosion is shown in the gullies and ravines along the sides of certain cones (p. 126); and in the South Pacific, Dana describes some of the cones of long quiescent volcanoes as so worn down that their outer slopes display little more than narrow ridges, with nearly vertical walls, separated by flat-bottomed valleys, which gradually contract towards the interior; and "at the head of each valley may be seen a little rill of water leaping from crag to crag, still carrying on," Mr. Browne remarks, in commenting on this passage, "the work of erosion to which at first sight it seems so utterly inadequate." Of course, if the volcano continues active at short intervals, the loss by the weather is soon recouped by the fresh material ejected. But in the cases where the "ribbed structure" is most prominent

the volcano is usually quiescent or extinct, though, as we have seen, these words admit of only a vague meaning. Then the wind and the rain, the winter snows and the spring freshets, the frost which freezes the water in the interstices of the lava, and by thus expanding it to greater dimensions than it formerly occupied, rives the lava asunder when the thaw comes, have "the game all to themselves." Thus in time only a stump of the old cone will remain, while, if the volcano is only slightly elevated above the sea, the waves may before long attack and utterly demolish every vestige of it. On the other hand, if it is spared this last misfortune, traces of the crater and volcano generally will remain for unnumbered ages, as the well-marked extinct volcanoes of Auvergne, in Central France, and the Eifel, in Central Germany, so abundantly prove. The entire plain of the Limagne d'Auvergne is dotted with these silent cones and dome-shaped hills, to the extent of about seventy, the average height of which varies from 500 to 1,000 feet above the level of the plains. But highest and most remarkable of them the Puy de Dôme is 4,000 feet high, though the shape of the cone and the lava stream may be even more easily traced in some of the smaller ones, such as the Puy de Come, 900 feet high, which looks as if it had been in eruption only a few years ago. The crater of Mont Dor, 6,000 feet in height, is so ruined that the only traces of it consist of a group of seven or eight rocky summits, circling round an area of about three miles, while the sides of the cone are channelled by deep ravines and subsidiary watercourses, which, in the course of long periods, during which the crater has ceased to belch forth the entrails of the earth, have cut deeper and deeper into the ashes, lava, slag, and other materials which are disposed here, just as they are in more modern cones.* Those of the Eifel, not to enumerate other less marked portions of Europe, are equally notable, some of the best preserved being easily seen by the tourist who takes the picturesque road from Gerolstein to Cochem, on the Moselle. Indeed, on the other side of the Kyll, opposite to Gerolstein, the Papenkaul affords a good specimen of a small extinct crater, from which a little stream of lava flows through a grassy valley into the romantic Kyllthal. Not far away is the Dreiser Weiher, a marshy meadow, notorious for its exhalations of carbonic acid gas, and the nodules of olivine, which, like the gas, are evidences of the volcanic agency so long at work in the neighbourhood. A mile from Dreis, close to the village of Dockweiler, is the Erensberg (2,198 feet), an extinct volcano, from which descends a broad stream of lava, and all over the adjoining region cones, craters, or portions of craters, slag, lava, ashes, overlying Devonian limestone, attest the activity which at one time prevailed in this now somnolent region.†

The cones may be formed of various materials. They may, for example, be built up of fine dust and stones, consolidated by pressure aided by water, or of mud, or of lava (like so many in the Sandwich Islands), or of a mixture of these materials, or even, as in the case of some of the Eifel cones, of nothing more than the fragments of the rocks through which the pent-up steam or gases had forced a way. Again, looking at them from a broader point of view, we may regard cones as falling into two great categories:—(1), Those in which, like the majority of volcanoes, the cone is built up of the materials ejected; and (2), the domed ones, composed of a homogeneous mass of lava, unmixed with other materials, and without anything in the shape of a crater or chimney, though it is quite possible that at different periods in their history the one might partake of the character of the other, and *vice versâ*.‡

Ringed Volcanoes. — It will sometimes happen that during a violent outburst the top of the cone, which it has taken centuries of

* Scrope: "Geology and Extinct Volcanoes of Central France" (1858); Lecoq: "Époques géologiques de l'Auvergne" (1867).

† Hibbert: "Extinct Volcanoes of the Basin of Neuwied, on the Lower Rhine" (1832); Von Dechen: "Geognostischer Führer zu dem Laacher See" (1864), and "Geognosticher Führer in das Siebengebirge" (1861); Vogelsang: "Vulcane der Eifel" (1869), &c.

‡ Von Seebach: *Zeitschrift der Deutsch. Geol. Gesellschaft*, vol. xviii., p. 644.

KAWA RATU OR THE KING'S CRATER

THE ACTIVE CRATER OF TANGKUBAN PRAHU VOLCANO IN JAVA

(AFTER A SKETCH BY HOCHSTETTER).

slow, steady eruptions to form in the manner described, will be blown off, so that the volcano will then present the appearance of a huge sugar-loaf with the top quarter cut off. But, of course, if the eruption goes out after the old fashion, the materials belched out of the summit crater will speedily again form a new cone. But as this cone will naturally be smaller than the piece blown off, the new one will appear, for a time at least, encircled by the summit of what remains of the old one as if by a ring, between which and the new cone reared inside of it there is a vacant space. Many examples of this volcanic appearance are afforded by existing volcanoes. For instance, a good illustration of such a composite volcano is seen in Vesuvius. We have already learned (p. 120) that the first recorded eruption of this mountain was in A.D. 79. At that date the peak now known as Vesuvius seems to have been formed. Before that occurrence the mountain had been topped by a rounded crater, the south side, where Vesuvius now rises, having been the lowest. This crater now encircles Vesuvius with the half ring, called Monte Somma, while the space between the two is the sickle-shaped valley, well known as Atrio del Cavallo (Fig. 70).

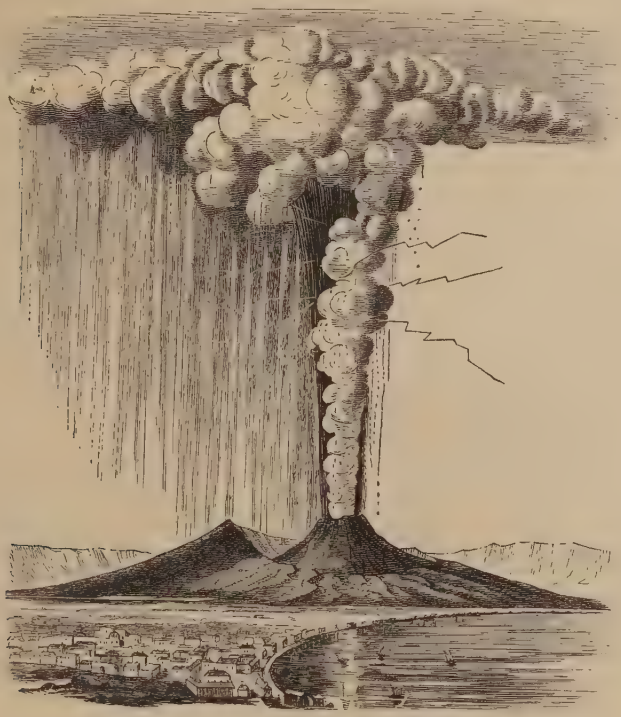


Fig. 70.—SOMMA AND VESUVIUS, THE ONE ENCIRCLING THE OTHER.

(An example of the ringed volcano, with the eruption of Oct., 1822.)

Since the year 79 the summit of Vesuvius has undergone several changes, sometimes after an eruption, a single crater, and sometimes two or three craters close to each other, making their appearance. The mountain itself, which rises from the sea at an angle of 10°, while the cone has a gradient of 30°—35°, has not much altered, though its height has undergone some change after

nearly every great outburst (p. 120). It is, therefore, quite possible that by the summit of Vesuvius breaking off, a second ring may be formed, and, indeed, cases might be mentioned as the newer cones formed within the ring of the older ones, composed of Santorin and Therasia (Fig. 72).

Von Seebach has described the eruption

Fig. 71.—THE PEAK OF TENERIFFE.

a, The Peak; *b*, the *débris* left in the valley (Atrio) by the volcanic eruption of the central peak or cone; *c*, the ring or the old crater; *d*, streams of lava flowing out of the Atrio.

in which even three can be traced. Among these ringed volcanoes the Peak of Teneriffe may be mentioned. Here the central cone rises high above the encircling crater of its truncated predecessor (Fig. 71).

Barren Island, in the Bay of Bengal, might also be cited as a fair example of the ringed volcano. The Greek island of Santorin is also an instance of the same physical feature. It and Therasia form the ring of a crater, most of which is now under the sea, but still occasionally active, the eruptions of modern times venting through the little islands in the central lagoon, which islands may be regarded

which resulted in the birth of the two "Kaimeni" (literally, that which is burnt), in 1866. On the last day of January convulsive movements were felt on the island, and the land was observed to gradually sink. The sea came rapidly in, but a boiling fountain

Fig. 72.—VIEW OF THE VOLCANIC ISLAND OF SANTORIN, IN THE GREEK ARCHIPELAGO, DURING THE ERUPTION OF 1866.

a, Thera, or Santorin; *b*, Therasia; *c*, Aphroessa; *f*, *g*, Nea and Mikra Kaimeni left by the eruption of 1866; *h*, Palaä-Kaimeni.

was soon observed to have been formed, and by the 1st of February was surrounded with lumps of lava and *débris* which floated on the surface of the sea. This fountain gradually rose just above the surface, and continued to emit flames. Then a succession of eruptions took place during the night, and were scarcely noticed until it was seen that a little volcano

had developed on a miniature island, which was named after King George of Greece (Fig. 73). This George volcano became so defined that Nea Kaimeni, adjacent to it, grew into an island formed out of the *débris* vomited forth, and in time the lava and other erupted matter formed the tiny islet of Aphroessa. In the second half of February, 1866, the activity of the volcano ceased, and was lying in the channel between Nea and Mikra Kaimeni, received on its fore-deck a glutinous lava-bomb, and was covered with dust; while a small vessel lying in the neighbourhood was driven on Santorin, where the captain was killed, the timbers of the ship were destroyed, and the whole ship was engulfed in the flames. Owing to a Greek commission having been despatched to the

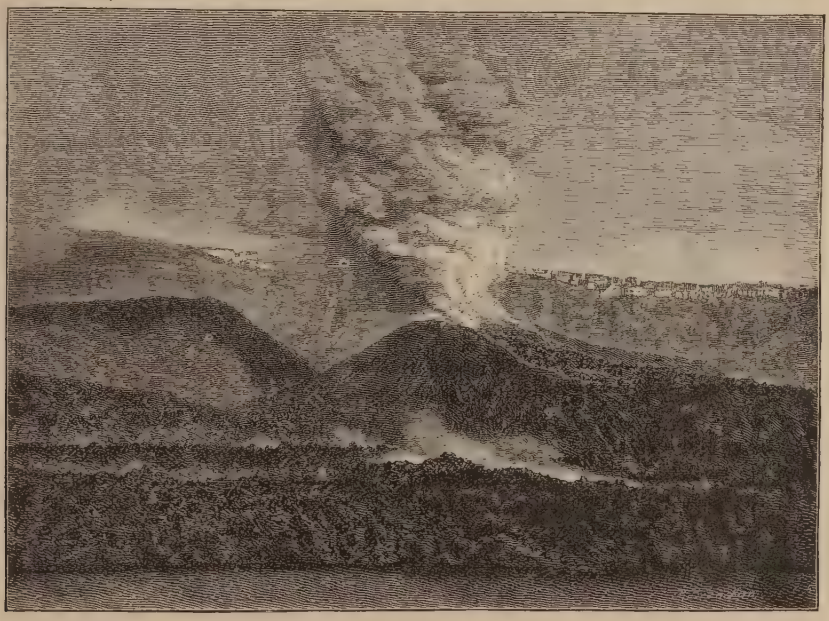


Fig. 73.—ERUPTION OF THE GEORGE VOLCANO, ON NEA KAIMENI, 1866.

the place where it had been in eruption became a solid rock. During the activity of the volcano the rumblings could be heard at a great distance. They were much louder than thunder, though the tone acted on the nerves like the shrieks of a shrill fife. This noise was produced by the emission of steam and gases through a small aperture. At a distance of 9,000 feet, the rubbish and ashes that were ejected from this miniature volcano were found to include many blocks of lava. The houses near Kaimeni were entirely destroyed, and a large block of lava damaged the Catholic church. The Greek gunboat *Aphroessa*, which place, the circumstances under which the eruption occurred were clearly observed. Numerous specimens of half-hardened lava were obtained, and small pieces fell into the pockets of members of the Commission, and destroyed their clothing, though, by wondrous good luck, the owners escaped further injury. In the month of March the great outflow of ashes and lava ceased, and the flames—bluish-white in the interior, carmine-coloured on the outside—no longer played so weirdly round the outpourings of molten rock. But the shrill sound—half roar, half rattle—resembling that of an engine entering a tunnel,

remained as before. Then the island heaved as if in convulsions, remained motionless for a moment, and soon disappeared, the ashes, lapilli, and great blocks falling last. On the 9th of March a new rock arose at Aphroessa, which was named after the Austrian gunboat *Reka* lying close by.

From 1866 to 1872 the volcano of Santorin did not show any symptoms of activity; but in 1870 it was noticed that George volcano had risen to a height of 354 feet, and that Nea Kaimeni itself was beginning to exhibit traces of eruption. The new volcano showed itself as a rounded body, about 354 feet high, and with sides at an angle of 32°, covered with ashes and great blocks of rock. Near the peak, and half-way up, there were noticed yellow-green streaks of sublimed sulphur, which covered the ashes with a fine dust, indicating that the sulphurous smoke pressing through the crater walls was accompanied with free hydrogen, largely evolved by Santorin and other volcanoes, and probably the source of the lambent flames already noticed. The plateau of the crater whence these blocks of stone were derived is of such a character that it is hard to conceive of lumps much larger being sent from this quarter. From day to day the stony crest of Santorin altered, and, according to the varying shapes of its crater, exhibited various changes of form. The successive eruptions took place at intervals of about six to ten minutes, but during the night a constant deafening roar was kept up, and the heat of the glutinous blocks ejected was such that each of them formed a separate island, as it were, in the shallow water around.

Santorin is believed to have been elevated at least 900 feet above the sea, since first it was disturbed by volcanic action, for in tufas of that height marine shells have been found. But there is also evidence that at the time it was blown up by that explosion—or "Hephæstus" as the islanders, using the old divine name to denote "fire," call the volcanic force—people had already settled on the island, for remains of buildings, vases, and pottery, have been found under the piles of volcanic ejections. The catastrophe was no doubt sudden, and seems to have entirely destroyed the inhabitants of the island,* though, so far as we have been able to learn, no legendary survival of this catastrophe is to be recognised in old Greek story. Finally, though the island of St. Paul, in the Indian Ocean, is, in common with Santorin, a good example of the result of a submarine volcanic eruption, it also serves as a not inapt type of a volcanic cone with a parasitic cone and crater, and of a crater which has formed the bosom of a lake, in this case of salt water, though in the instances to be presently described the craters are filled with fresh water (Fig. 74).

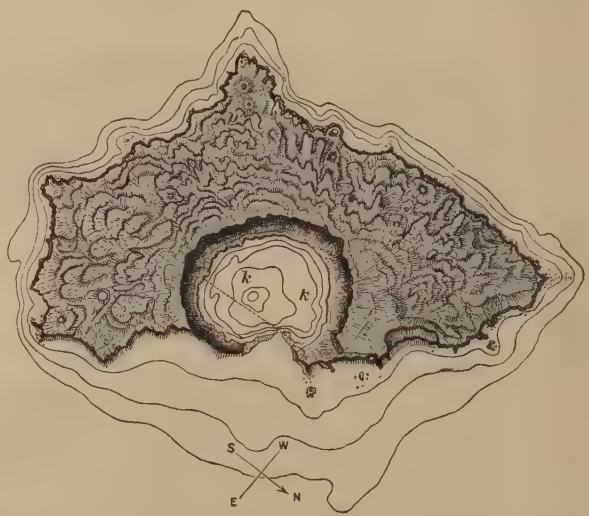


Fig. 74.—ST. PAUL'S, A VOLCANIC ISLAND IN THE INDIAN OCEAN.

k k, the crater; *p*, a parasitic cone and crater, marked by a deposit of slag.

Crater Lakes.—A crater is, as the word means,† a cup, and every cup left long in the open air will sooner or later get filled with water derived from the rainfall. Accordingly, this has happened in the case of many old

* Arch. Geikie, in *Contemporary Review*, Oct., 1886; Bent: "The Cyclades" (1885).

† *Krater*, Greek for a cup.

volcanoes situated in wet countries. The sides of the crater being unbroken, and the basin itself extending to a considerable depth, the snow collects and melts in the hollow; the rain and springs also often contribute to the supply. The result is a deep lake in the cavity out of which fire and boiling rock at one time belched (Fig. 75). To render the crater fitted for holding the water thus accumulated, the pipe leading down to the old internal reservoirs of volcanic matter must, of course, be stopped, and the walls of the basin composed of tolerably impervious matter; while a certain depth and internal shape are requisite, otherwise the water would escape, and, by breaking down the walls in the manner described (p. 126), not only prevent the formation of a permanent tarn, but soon render the crater unequal to the formation of a lake basin. Hence, as not a great many craters combine all of these conditions, the number of "explosive lakes," as they are sometimes called, is comparatively few in proportion to the number of extinct volcanoes; and as some of them are now surrounded by vegetation, it requires a practised eye to detect their real character. They are, however, found in many parts of the world, though those most familiar to geologists are in Auvergne, Central Italy, and the Eifel, where they are known as *maare*.

In all parts of the district last mentioned they are very well marked. Accordingly, a few remarks may be added on the most notable of these, derived from personal observation, supplemented with details selected from the ordinary sources of information on the topography and geology of the Rhineland. A few miles from Daun, a village surrounded by slag hills, lava streams, volcanic sand, "lapilli," —*i.e.*, small, round nodules of lava—and mineral springs, is the Förmerich crater, filled with ashes, from which runs a lava stream, on one branch of which, taking the columnar form, the castle of Daun is built. But the three Dauner Maare are more to our purpose. The Gemündner Maar is 1,282 feet high, and about 200 feet deep. The Weinfelder Maar and the

Fig. 75.—CRATER LAKE OF TAAL IN LUZON, ONE OF THE PHILIPPINE ISLANDS.

Schalkenmehrer are both larger; but the latter being drained by the Alfbach is not more than one hundred feet in depth, though, like most of the lakes, it is full of crayfish and different species of fish. The Pulvermaar of Gillenfeld is about 300 feet in depth, and surrounded by banks of volcanic sand, tufa, and the loose form of lava known as scoriæ, though the immediate walls of the crater are chiefly the ejected matter and shale and sandstone through which the old volcano burst, the lake itself lying at a depth of about 150 feet below the surface. The Meerfelder Maar, though hollowed out of similar strata, and surrounded by heaps of pulverised shale, containing few volcanic substances proper, is of much greater size and depth than those named. It is nearly a mile in diameter, and was at one time nearly 500 feet in depth, though now almost entirely drained. The scoriæ and sand of the large lava mountain called the Mosenberg, with its four craters (the northernmost of which was formerly filled with water, but, after being drained in 1846, now yields peat), are also found in the heights around this maar. Passing from the Upper to the Lower Eifel, we come to the famous Laacher See, six miles in circumference and 173 feet deep in the centre. This lake, however, though generally classed among the crater water-basins, is now generally believed to have been formed by an eruption of the wooded Veitskopf, a volcanic peak with a double crater and a broad lava stream. Sir Charles Lyell, however, seemed to have regarded the Laacher See as a true "maar," for he notices its resemblance to the Lago de Bolsena and others in Italy, in so far that it is surrounded by a ridge of gently sloping hills, composed of loose tuffs, scoriæ, and blocks of a variety of lavas.* Not far from the lake is a "mofette," or hollow, whence a suffocating stream of carbonic acid gas arises. In the thirteenth century an inundation of the Laacher See having threatened the abbey lands of Laach, the monks sunk a shaft in the south side of it by which the superfluous water was drained away, and another sunk in 1845 lowered the level of the lake twenty feet. These crater lakes of the Eifel are sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on an intervening platform, and the volcanoes to which they owe their existence seem, for the most part, to have burst into eruption after the present system of hills and valleys had been formed. Lyell, in noting this, remarks, as less scientific tourists must have done, on the suddenness with which one comes upon them in travelling through the district. No sign of volcanic action more than usual is observed when unexpectedly the pedestrian finds himself on the very edge of a crater, and down below the deep, clear water gleaming, when it can catch a glimpse of the passing sun. Indeed, the comparatively small amount of true volcanic materials in so extremely volcanic a district, indicates that the force which tore up the strata was gaseous explosion, attended with a moderate discharge of lava, but much glistening volcanic sand and pumice. This, with fragments of lava, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees, forms the basis of the tufaceous alluvium locally known as "trass," which covers large areas in the Eifel, and chokes up some valleys. It seems to have been formed during the period of the eruptions.

The Lonar Lake, half-way between Bombay and Nagpore, is another noteworthy crater basin. It is over a mile in circumference, and from 300 to 400 feet in depth, but the actual water in it is shallow, and of a saline bitterness, though it is evident that at one time it was very much fuller.

Recently another remarkable crater lake has been discovered on Kilimanjaro, a snow-capped mountain in Central Africa, which is little short of 19,000 feet in height. This is Lake Chala, about three miles long by one wide, lying at from 400 to 800 feet below the level of the summit, and with banks so steep that

* A fuller account of these lakes may be found, so far as their topography is concerned, in all the best guide books to the district—especially the familiar "Baedeker" and "Murray." Their geology is, however, more exhaustively treated in the works already noted (p. 128). But for English students there is no better short description than that of Lyell in his "Principles of Geology" (4th Edit.), Vol. IV., pp. 49–61, which is practically the same as in his later works, though better illustrated.

a descent to the water is impossible, except at one place on the western side. But though the lake has no apparent inlet or outlet, being fed by rain and melted snow, the water is clear, cool, and perfectly sweet. It contains numerous fishes, and is frequented by flocks of water-fowl, the flapping of whose wings produces a noise, through confused reverberation in the deep, well-like basins, like the rushing of a distant railway train. The cries of the birds had a peculiar sound, and Mr. Wray, who reached the edge, had no doubt that it was their noises which gave rise to the native myth, which tells how a Masai village formerly stood here, but was swallowed up by the tarn, the people of Taveta believing that they hear voices, the lowing of cattle, the bleating of sheep, and so forth.*

But the most remarkable of all the crater lakes is one in the Cascade Range, in Southern Oregon, of which the writer believes that he for the first time, over twenty years ago, indicated the true character. The lake, according to the latest and most accurate description—that of Captain Dutton, of the United States Geological Survey †—is about seven and a half miles long and five miles wide, in shape nearly elliptical, without bays or promontories, and girt by a complete crescent of cliffs, varying in height from 900 to 2,200 feet, and in which the only narrow spaces for lodgment are where the rains have scoured gullies in the perpendicular walls. Any visible outlet has not been discovered, and the only feeders of it, besides the snows and rains, are the little rills of water flowing from springs in the faces of the walls. But as the evaporation in this part of the world is less than the precipitation, there must, as in all of the crater lakes of Europe, be some underground mode of escape for the superfluous water.

This crater is, moreover, a specimen of the ringed variety, for in the lake is a cinder cone 600 or 700 feet high, having "the usual cup or hopper" on its summit, and, though covered with timber, it is still very little eroded. Two streams of lava stretch out from its base towards the great well, but do not reach it, so that the insulation of the cone and its lavas is still complete. The water is of an intense ultramarine, and reflects in the most perfect form every portion of the circling cliffs. But it is not so much the beauty of this picturesque spot which commands attention, or the interesting geological features which it exhibits. The island in the centre is in all likelihood a cone, which at one time rose high above the encircling walls of the Somma-like old crater surrounding it (p. 129). But Captain Dutton does not venture this opinion. All that he suggests is that the crater is a "caldera" (p. 125), formed by the summit of the old cone having been removed, either as those of the volcanoes of Hawaii have been (by the lava draining off through openings miles away and thousands of feet below the summit, thus depriving the upper portion of the mountain of the liquid support which held it up, and compelling it to sink into the caldera), or by the top being bodily blown off (as, among other instances, in the truncated cones of the East Indian Archipelago, more particularly Papandayang in 1772, and Tomboro in 1815). The outburst of the latter surpassed even the tremendous outbreak of Krakatau in 1883. Prior to this eruption Tomboro, on the island of Sumbawa, was a sharply-defined cone rising to the height of 9,000 feet. But in a single night the upper 5,000 feet were blown into fragments, which were scattered over thousands of square miles of land and sea, while the volcanic dust darkened the air over a million square miles of island and ocean. When the scene could be visited in safety, several months later, Tomboro was "a mere stump of a mountain, with a large crater, or caldera, in the place of the cone which had been blown away."

Some such catastrophe seems to have befallen the cone of which Crater Lake is now the summit. The deep ravines (p. 127), with their boundary ribs, which score its sides,

* *Proceedings of the Royal Geographical Society*, 1887, p. 47; Thomson: "Through Masai Land" (1885), pp. 217, 229.

† *Science*, Vol. VII., No. 160 (1886), pp. 179–182, and Vol. VIII., No. 186 (1886), p. 177.

as is the case in the neighbouring mountains, end abruptly just at the brink of the pit, and the neighbouring country is strewn with vast quantities of tufa and of pumice, varying from pieces a cubic foot in volume to fine light sand. Vast quantities of it have been gathered up by the rivers and streams (for it is lighter than cork), and swept eastward into the broad basin of the Klamath Marsh and Klamath Lake, or carried westward through the Rogue river into the Pacific. The finer lapilli and sand have been consolidated into beds which flank the eastern side of the Cascades, and are found on the western slope in the flatter spaces beyond the base of the truncated cone which holds the crater and its lake, while the tuff has weathered into "pleasing columnar forms." Most probably the mountain, before it met with its mishap, was not a sharp or lofty cone—like Mount Pitt and Mount Scott to the south, and Mount Thielson to the north—but like so many of the Cascade peaks—Union Peak, to the east of it, among others—of a dome shape or flatter form (p. 128).

The only difficulty in accepting this ingenious theory—and the difficulty is of Captain Dutton's own raising—is that we do not find the *corpus delicti*, as we might expect to do when a cone of solid lavas, such as now line the Crater Lake, was "blown into rubble," and the fragments hurled far and wide over the surrounding country. No fragments have been noted, except such as are usually found at the foot of steep spurs and ridges of volcanic rock. Yet it is hard to divest oneself of the conviction that this admirable observer is right, with or without the addendum regarding the secondary cone forming the island which we have proposed.

The depth of Crater Lake is, on an average, 1,490 feet, though the soundings vary from 853 feet to 1,996 feet, with the probability that there are spots exceeding this in profundity. But so abrupt are the walls of this tarn that at four or five hundred yards from the shore the lead sinks to fifteen, and even eighteen, hundred feet all round the margin. Crater Lake is thus the deepest body of fresh water in the world, unless, indeed, similar tarns may be discovered in some of the many unexplored volcanic ranges of the New World. Though this is, to some extent, anticipating the discussion of lakes proper, it may be well to give in this place a comparative list of the depth of other lakes, but it ought to be noted that some of those which appear shallow, compared with the one described, are in reality even more interesting, since they are not due to volcanic agency, but to erosion by glaciers, or to the other means which (we shall learn in time) have been at work in forming the spaces now occupied by sheets of fresh water:—

Fresh-water Lakes.	Height of Surface above Sea.	Maximum Depth.
	Feet.	Feet.
Temiscouata (Eastern North America)	400	500
Superior (ditto)	609	1,010
Michigan (ditto)	582	864
Huron (ditto)	578	705
Erie (ditto)	573	324
Ontario (ditto)	247	738
Tahoe (California)	6,247	1,645
Crater (Oregon)	—	1,996
Leman (Switzerland) ...	1,226	1,017
Como (Italy)	699	1,926
Maggiore (Italy)	686	2,612
Baikal (Asia)	1,360	12,356

Some of these depths are, however, doubtful. For instance, the maximum depth of Huron must be considerably higher if, as is said to be the case, soundings have been taken to 1,800 feet without finding bottom. As for Lake Baikal, a judicious geographer will maintain a discreet scepticism towards the depth given.* Nor are these lakes without their geological as well as their geographical interest. Let us suppose that one of them was emptied by any internal disturbance, whether in the shape of an earthquake or a volcano. The

* Le Conte, in *Science*, Vol. VIII., No. 200 (1886), p. 516. Some Russian surveyors put the maximum depth of Lake Baikal at upwards of 300 fathoms, *i.e.*, 1,800 feet—though likely enough there may be holes in the bottom stretching to almost any profundity.

result would be that the lake in the crater would either be released by the breaking down of its surrounding walls—in which case an immense torrent would sweep everything before it, and most likely alter the physical features of the region over which it rolled—or the water would be tossed up by the forces beneath in hot showers, mixed with unstratified alluvium, the base of which consists almost entirely of pumice-stone, in which are embedded fragments of lavas, and pieces of other rocks which have evidently been subjected to volcanic influences, with numerous trunks and branches of trees. This trass would again be produced if an eruption occurred and a flood from the crater lake

Fig. 76.—ERUPTION OF MAUNA LOA (HAWAII, SANDWICH ISLANDS) ON THE 14TH OF FEBRUARY, 1877, AT 9 P.M.

N, North; S, South; †, Crater of Mokuaweoweo; † †, Mauna Loa; † † †, Central Plateau; † † † †, Mauna Kea; † † † † †, Kau; A, Kawaiahae; B, Hualalai. (*After a Sketch by M. Th. Ballieu, French Consul at Honolulu.*)

volcanic ashes and other *débris*, and fall in the shape of a peculiar deposit, which would cover the surrounding country, though its origin might puzzle the geologist.

That such an event is quite possible is proved by several facts worthy of notice. In the first place, such a catastrophe seems to have happened at some former period in the history of the Eifel volcanoes. The "trass," which covers large areas of the Eifel, is an swept over the country, carrying before it the woods, with the more recently discharged products of the eruption, and then depositing them after it had subsided into a heterogeneous mass, in every respect corresponding to the one described, which, moreover, from its conforming itself to the shape of the valleys, appears to have been deposited since the country assumed its present form, and therefore to be comparatively modern. Indeed,

nearly every volcanic eruption is accompanied by more or less water. This in many cases comes from the crater lakes, or from reservoirs which have accumulated still deeper in the earth, and been disrupted by the explosion, and, when mixed with volcanic dust and ashes, it forms the "mud lava," so dreaded of the people in the vicinity. It was this "lava d'acqua," as the modern Italians call it, not the true lava and melted rock, which in A.D. 79 enveloped Herculaneum in its "tufa" folds, and which in 1822 buried many of the streets and houses of Ottajano and Massa. The "moya" of the Andes may, no doubt, in some cases be of a similar origin. But in the majority of instances it is due to the melted snow and ice sweeping down the side of the mountain in eruption, tearing up great ruts in its course, and carrying before it the vegetation which has sprung up during the period of quiescence. During an eruption of Cotopaxi, in June, 1877, villages miles away from the mountain were buried under the moya, mixed with lava, ashes, wood, and all the other *débris* which it had met with in its headlong rush. Indeed, so rapidly did it travel that great blocks of ice survived the voyage into the tropical lowlands. The mud discharged from so many of the Central and South American volcanoes may be traced to water gathering in places near the crater, and then getting thickened into mud by the loose volcanic dust and ashes which are so plentiful in such quarters. Then, when the outbreak comes, the accumulation is sent skyward. But in other instances the volcanic discharge may tap lakes or ponds of pure water. This must assuredly have been the case in 1691, when Imbaburu, an Ecuadorian volcano, emitted floods of mud, so plentifully charged with dead fishes that the stench which arose from their decay gave origin to a pestilence in the town of Huera. Seven years later, Carguairazo, a lofty peak in the same range (17,500 ft.), sent torrents of mud out of the crater, this mud containing immense quantities of a species of fish known as "Preñadilla" (*Pymelodus cyclopum*),* and much the same facts have been recorded of Cotopaxi, Tunguragua, and Sangay. In this particular instance the top of the cone is said to have fallen in, so that if, as is not unlikely, a lake had accumulated in the old crater, the mud must have been of very recent origin. At all events, when fishes are found, it is perfectly certain that they could not have been long in a reservoir of mud. The "moya," though it sometimes escapes from the crater, and sometimes from openings on the side of the cone, is also of surface manufacture. This is shown at once by the fishes which it so often contains being the same as those found abundantly in the neighbouring streams above ground. The chances are, therefore, in favour of its being an accumulation of much the same character as those already indicated. Finally, there is no reason for supposing that the vast outpourings of mud by which the Java volcanoes are distinguished are essentially different in their nature. We know that crater lakes are found in those regions. For example, during the eruption of Idjen, in 1817, an accumulation of this kind, hot and charged with volcanic acids, was emptied down the slope, and, after the eruption ended, reformed, though the water, instead of being hot, was of nearly the normal temperature. In 1800 Guntur discharged an acid torrent, and also rivers of mud. At times wide tracts of luxuriant vegetation have been buried under masses of "dark-grey mud, sometimes 100 feet thick, with a rough, hillocky surface, from which the top of a submerged palm-tree occasionally protruded."† In the second place, what has once happened may at any moment happen again. Whenever a volcano is quiescent for any length of time and its crater suitable for the collection of water, and the country in which it is situated not too arid, then it is almost certain that a crater lake will, in one shape or another, make its appearance, though it is not often that the

* It appears to frequent dark caverns.

† Archibald Geikie: "Text-Book of Geology," pp. 216, 217; De la Beche: "Geological Observer," pp. 366–406; Daubeny: "Description of Active and Extinct Volcanoes," p. 409.

accumulation of water is on the surface, or in so picturesque a form as in the examples cited.

More frequently the rain and melted snow find their way into some subterranean cavity, there to wait the time when they will be evicted by the forces from beneath. Most likely it was some such underground reservoir which, on the night of September 11th, 1541, gave way during an outbreak of the long-dormant Volcan de Agua, in Guatemala, and swept the greater part of the ancient capital into ruins and drowned thousands of the inhabitants. Nor is there any ground for believing that some such catastrophe may not recur. Indeed, though the volcanoes of the Eifel are characterised as extinct, Vogelsang has given us reasons for suspecting that the volcanic energy beneath the "maare" is only slumbering, and may, when least expected, rouse itself out of its uneasy sleep.

CHAPTER VII.

Volcanoes: their Phenomena, History, and Products.

General Phenomena of Volcanoes—Preliminaries of an Eruption—Etna as an Example—Products of Eruption—Steam and Gases—Reservoirs of Gases in the Earth—The Petroleum Region of the Caspian—Scoriæ and Ashes—Volcanic Bombs—Lava—Eruption of Hawaiian Volcanoes—Some other remarkable Eruptions in Sicily and Java.

The general phenomena (Fig. 76) attending a volcanic eruption will have been inferred from the details given. The rumbling sounds mentioned are usually the first sign of something going to happen, and not unfrequently earthquakes precede the first outburst. If the volcano does not act all the more precipitately, subterranean water-courses and an irregular ebbing and flowing of the sea will sometimes indicate the disturbance going on underneath. But this is not always the case. Often the first intimation of the mischief to follow is a loud explosion, followed by an ejection of steam high into the air, and then falling in a few minutes in the shape of rain. About this period the scared dwellers in the vicinity think it prudent to flee from the wrath to come, for soon after, dust, ashes, and stones are ejected, followed by larger blocks, sometimes of old lava, or of the rock through which the volcano originally burst, and the so-called "volcanic bombs," while flames appear to play round the summit. These flames are, no doubt, frequently lighted hydrogen or other gases, though in many instances they are simply the reflection of the molten lava rising up in the funnel of the crater, and giving a refulgent glow to the misty clouds and steam hanging over the summit. All the time explosions continue. But soon the lava begins to pour down the sides, out of the summit crater, or from some collateral openings in the side. After this pumice and black sand—like the "augite sand" of Stromboli—generally very finely comminuted, succeed; but in not a few cases the first outburst of steam, and the dust, ashes, and striæ which follow, constitute about all the phenomena of the eruption; while in other cases, after the steam has heralded what is coming (the steam being really the boiled water in the crater, or that of some subterranean cavity), the lava begins to pour over the cup (or crater), into which it wells up. This is the case in the Sandwich Islands (Fig. 76), where lava is the principal product ejected. In the Icelandic volcanoes there is also an immense discharge of lava; while in the Italian ones the ashes and other minor ejections predominate.

In Etna the course of an eruption is tolerably regular. Earthquakes generally presage them; then come loud explosions; rifts and *bocche del fuoco* (literally, "mouths of

fire") open on the sides of the mountain, and smoke, sand, scoriæ, and ashes are discharged. Then the action usually localises itself into one or two craters; cinders are thrown out, and accumulate round the crater in a conical form; ultimately lava rises through the new cone, frequently, Mr. Rodwell tells us, breaking down one side of it where there is least resistance, and flowing over the neighbouring country, carries before it great blocks of old lava, until to the casual observer it appears to consist simply of a river of *débris* borne down the slope. Then the eruption is at an end; and of the eighty or more on record, very few have diverged from this routine, or have been of extreme violence. Indeed, most of the outbreaks of this volcano—"famoso, immenso, terribile," as it has been termed—have been of a slight and comparatively harmless character (Fig. 77).

Products of Eruptions.

We are now in a position to discuss more fully the materials mentioned, and the conditions under which they are ejected from the volcanoes. Some of them, we have seen, are merely the ordinary obstacles which the force causing the eruption meets with in its course, such as the rocks through which it bursts, or water, either as water or as water converted into steam. In other cases they are the materials of the upper crust, or of the interior beyond our reach, which have been altogether transformed by the action of the heat which universally accompanies a volcanic outburst. Among these the various gases, the ashes, and, above all, the lava, may be mentioned. It may be added that though the amount of any one of the substances which will be briefly described in the following paragraphs varies in every mountain, in very few are they entirely wanting, though in the sudden turmoil which accompanies and follows the phenomena which form the theme of these chapters, one of them, if not very prominently present, may escape notice.

Steam and Gases.—Steam is invariably discharged during an eruption, though generally, as we have seen, as the forerunner of the other substances to follow, but the various gases continue to be ejected as long as it lasts. The steam forms the "stone pine-" like cloud which usually hangs over a cone, and, combined with the gases, greatly contributes to the loud explosions and the other noises which are such marked features in every volcanic discharge. It may even happen that after a time, as in the case of the Solfatara, near Naples, steam and gas—in the case in question sulphurous acid—will be discharged. The gases are mainly carbonic acid, hydrochloric (muriatic) acid, and the sulphurous acid gas which is so commonly associated with volcanoes, the evil-smelling sulphuretted hydrogen, and boracic acid; besides free hydrogen, which is believed to cause many of the explosions in the funnels of volcanoes, and the detonations and ejections of steam which follow; nitrogen, and ammonia. There are also secondary products springing from the combination of these gases with each other and with substances which they meet with in their way to the outer world. Thus, when sulphuretted hydrogen comes in contact with sulphurous acid, sulphuric acid (oil of vitriol) is formed and sulphur deposited. This sulphur is found in greater or less abundance in every volcanic region; while sulphuric acid, by combining with soda, lime, etc., forms the various sulphates of those substances which have already been more or less passed under review (pp. 67, 68). The amount of steam discharged depends entirely upon the amount of water which the volcanic heat finds to convert into vapour. This may be greater or less, according to circumstances, though, as even the driest of rocks contains much (p. 111), we need not be surprised at the steam ejected by one of the parasitic cones of Etna having been calculated to amount during an eruption of 100 days to 462,000,000 gallons of water.

The source whence the gases are derived is not quite so obvious, though, as the earth contains reservoirs of many of them, it is fair to conclude that they owe the fact of their being ejected during an eruption to the same mechanical causes which send the water with

which the volcanic force comes in collision into the air. The gas wells which occur in various carboniferous and petroleum districts, such as the United States and the Caspian, where they are utilised for giving light and heat are of this character. Most likely they are due to the same distilling processes (p. 65) which have resulted in the formation of the petroleum deposits. Often, when boring for the latter substance, these gas reservoirs are

Fig. 77.—CRATER OF MOUNT ETNA IN 1834.

"struck," and indeed they are not unfrequently found associated with coal-beds in England and elsewhere. In various parts of the United States they are employed to light mines and smelt iron, and for other economic purposes. When present in great quantity, they will frequently force water and petroleum to the surface in the form of a geyser; and, indeed, it is not uncommon to see such a boring alternately discharging gas and water or gas and petroleum. The petroleum region of the Caspian is well known, though it is not till within the last few years that it has become the scene of a great industry in this substance. The vicinity of Baku has from time immemorial been deemed sacred by the the Hindoos; and for at least 2,000 years the sacred earth-fed flame has burned unceasingly, and the temple of Sarakhani been a centre of reverent pilgrimage to the adherents of the ancient faith of India.* This native naphtha flows from the soil in so pure a form that it burns without rectification, and is, indeed, so inflammable that the naphtha gas occasionally ignites spontaneously, and plays in pale flames above the fissures in the rock. On stormy nights these flames have been seen to blaze up with an awful spirit-light which, in the eyes of the superstitious, invested the spot with special sanctity—a sanctity intensified by the fact that here, according to Arabian chroniclers, a great volcanic mountain was in full action till 800 years ago. Since then the thermal forces have expended their energies on spouting oil, and therewith saturating the desert plain of the Apsheron Peninsula; nor truly could a more repulsive site for a great city well be found. And here, day and night, the oil-fountains pour forth their hideous black streams. The supply may well be deemed inexhaustible, inasmuch as 12,000 square miles in this region are found to be oleiferous, and of this vast surface only six miles have as yet been developed. The oil-bearing stratum extends beneath the Caspian Sea, where it crops up in Tchelikan, a true Isle of Oil. Here the oil literally streams into the sea from hills and cliffs which may be said to be formed of ozokerite (p. 64)—in other words, of crude paraffin. In the Caspian, not far from Baku, there are a number of gas escapes which when lighted set the entire surface of the sea in a blaze. On the eastern shore of the Caspian petroleum reappears at various points—as, for instance, at the Neft or Naphtha Hill, where the deposits are officially valued at £35,000,000 sterling. Then, again, as Baku lies at the eastern extremity of the Caucasus range, so at its western extremity lies an oil-field extending over about 250 miles. It terminates in the peninsula of Taman, between the Black Sea and the Sea of Azoff—a region abounding in active "mud-volcanoes" and occasionally shaken by earthquakes. Early in the year 1887 the fire-giant, this Asiatic Enceladus, who tends the great laboratory beneath the Caspian, seemed disposed to emulate the example of his brethren in New Zealand, Tonga, and Hawaii. Hitherto he had been satisfied with such sport as turning on an oil-stream like that which gushed forth three years before from one of the Baku springs, spouting with such force as to break to pieces a three-inch cast-iron plate which had been fastened over the well in order to divert the flow to a different direction. A neighbouring oil-spring, on being tapped, threw up a column of petroleum to twice the height of the Great Geyser in Iceland, forming a huge black fountain 200 feet in height—a fountain, however, attributed solely to the removal of the pressure on the confined gas, as there is no perceptible heat in these geysers. It was visible for many miles

* By a curious, though not unaccountable, mistake, this temple has been generally described as that of the Zoroastrians, or Fire-Worshippers of Persia, who in India are known as Parsees. In reality it is a Hindoo idol temple, like the fire temple of Juwalla Mukhi in the Punjab. The Russians have extinguished the flame—the gas being too useful at their factories to be kept blazing—and now it is only lighted for the amusement of visitors. Colonel Stewart, from whom we derive this information, declares that he never heard of any Parsee visiting the temple, and the Zoroastrians in Persia take no interest in it. There was at one time an idol in it; now the Persian Fire-Worshippers have nothing to do with idolatry. Moreover, the inscriptions on the wall are not in Pehlevi or any form of Zend, but in the Sanscrit character.

around; and on the first day it poured forth about 50,000 barrels, and, with gradually diminishing volume, continued to play for five months, when it finally subsided, leaving its unfortunate owners (an Armenian company) well-nigh ruined by the claims brought against them by neighbours whose lands were destroyed by the oil-flood. One house which stood near the spring now lies buried beneath a sand-hill (the cone of this "mud-volcano"), which alone marks the site of this too prodigal fount. Quite recently a still mightier naphtha-flow suddenly commenced playing with such vigour that a number of buildings were swamped. For some days it continued altogether uncontrollable, and fears were entertained for the safety of the town of Baku. Now, however, a more appalling terror has appeared in this region, where there is so enormous an amount of inflammable matter that one might well dread the kindling of the most carefully guarded flame. On the night of the 5th of February, 1887, the inhabitants of Baku were awakened by a violent shock which caused all the windows to rattle, and suddenly the darkness of the night was illumined by an intense light, as though the city were aflame. It proved, however, to be but the reflection on the heavens of a great fire at a distance, whose origin does not seem to have been comprehended till the following night, when the same awful glare became visible; and shortly before midnight a terrific explosion was heard, immediately followed by a vast column of flame, about 350 feet in height, which shot up from the summit of the Lok Batan, close to the Ponta railway station. It was a calm night, with scarcely a breath of wind; so the flames continued to ascend quite vertically, carrying large masses of dark matter, which fell back into the crater. Considerable heat was felt at the distance of fully a mile, and the whole country was lighted by a glare brighter than that of the sun at noonday. This lasted for about thirty hours, but not continuously, the column occasionally subsiding. The volume of liquid mud ejected in this period has overspread a track of about a square mile to a depth varying from 7 feet to 14 feet.* On the 22nd of March there was another explosion exactly similar. In other words, this was a discharge of gas from one of the two "mud-volcanoes" from which it ordinarily escapes near Baku. This class of phenomena—entirely different from the mud-discharging craters already described—may, however, conveniently be discussed in another chapter.

Again, every volcanic region seems to be charged with carbonic acid gas (carbon dioxide). This we have seen to be the case in the Eifel (p. 128), and the story of the Upas Tree Valley in Java, out of which no man could escape, though for the most part an invention, in reality owes its origin, not to the known circumstance of the *Antiaris* being a poisonous plant, but to the fact that in a valley in that island carbonic acid oozes so plentifully out of the soil, that the ground is strewn with skeletons of animals which have incautiously ventured into it and been suffocated by the poisonous stratum of the heavy gas lying over the earth like the thin mist which gathers in a valley towards evening, though in this case the fog being transparent it is all the more dangerous. Even in Vesuvius, Sir William Hamilton has put cases on record in which pheasants, hares, and other small game, were killed by breathing the emanation oozing out of the cracks on that volcano, and, in 1730, all the cattle in the island of Lancerota, one of the Canaries, were destroyed by the deleterious emanations from the volcanic soil.

But there are other gases connected with a volcanic eruption which are more directly dependent on it. As Bunsen, Leblanc, Sainte-Claire-Deville, Foqué, and other chemists, have shown, the amount and the order in which these gases are given off follow in tolerably regular sequence. For instance, lava as it cools and hardens sends forth hydrochloric acid, chlorides, and sulphurous acid; next steam, and then carbonic acid and combustible gases. In other words, the nature of the discharged vapours depends on the activity of the volcanic vent

* Miss Gordon-Cumming in *St. James's Gazette*, Feb. 15th, 1887; Col. Stewart, in *Murray's Magazine*, April, 1887.

and the temperature of the underground scene of its activity, chlorine indicating the most violent stage, sulphurous acid a less active one, and carbonic acid the fact of the energy being reduced to its lowest ebb.* It is found, moreover, that volcanic discharges are attended with certain electrical phenomena, owing, it is believed, to the electricity developed by the friction of the uprushing current of steam against the walls of the crater funnel, and to the collision of the fragments of rock against each other. Lightning, for example, often plays round a volcanic crater in eruption (Fig. 70), and in the earliest stage of the discharge loud claps of thunder are frequently heard.

Regarding the source of these gases, there is still room for some speculation. Siemens believed that the free hydrogen which is discharged by many volcanoes—and which when lighted is the origin of the true flames which it is now known really do exist in eruptions, in addition to the reflections sometimes mistaken for them (p. 139)—is plentifully dissolved in the "magma" (p. 85), from which the ejecta are supposed to come. Again, we know that lava and other volcanic rocks contain various compounds which, if decomposed under the action of intense heat, would evolve several of the gases mentioned; while carbonic acid (carbon dioxide) and sulphuretted hydrogen might, like the volatile hydro-carbons of gas springs in the petroleum and coal districts (p. 141), be due to the slow distillation of organic substances, and be connected with volcanic outbursts only in so far that the eruption has broken up the reservoir in which they have accumulated, and allowed of their free discharge into the upper world. It also follows that the different gases which we have described, by entering into combination with each other, and with other substances ready to unite, will form a long series of fresh chemical compounds, such as the many beautiful minerals found in the vicinity of every volcano, and the collection of which—as visitors are not long in learning—constitutes one of the chief industries of the people in the vicinity. The rumbling and shrieking sounds so often heard around active volcanoes are no doubt due to the explosions or escapes through narrow passages of these pent-up gases. When the Crusaders passed Stromboli, on their way home from Palestine, they affected to have heard the cries of poor souls in Purgatory, proceeding out of the centre of this volcano, which is regarded as the entrance to that land of expiation, imploring the monks of Clugny to say masses on their behalf. It was this tale which induced Odilo of Clugny to institute the festival of All Souls. It may be added that the ancients regarded Strongyle—as they termed Stromboli—as the seat of Æolus, God of the Winds, since, according to Pliny, the weather could be foretold three days in advance from the smoke of the volcano. It is still often affirmed that both Stromboli and Vulcano smoke most vigorously during the Sirocco wind, but the islanders affirm that the smoke is most copious during the west wind, or "Ponente."

Scoriæ, Ashes, etc.—These form the vast portion of the ejecta of many volcanoes, and may consist of all or of any of the rocks through which the volcanic force has burst, of others which it has ground into fragments, burnt into ashes, or fused into the slag-like cinders found in the vicinity of almost every cone. Others are fragmental portions of the lava detached from the main mass, in a semi-glutinous condition, like the pieces described as falling during the Santorin eruption, or merely red-hot stones of all sorts blown out by the force of the explosions of steam and gas. During the eruption of Vesuvius, in December, 1631, heavy stones were thrown to a distance of fourteen or fifteen miles, one which fell at the village of Somma weighing 25 tons. Sometimes these masses of rock take the form of what Darwin called "volcanic bombs."† These are frequently lumps of the rock underlying the cone, coated thickly over with lava, or are masses of lava spongy in the interior, and more or less smooth on the outside, their shape being due to the rotatory motion they take in rising to the surface (Fig. 78). Scoriæ

* Foqué: "Santorin et ses Eruptions" (1879).

† "Volcanic Islands," p. 36.

or cinders and the slag or clinker are to be looked for in such a huge forge; while the "lapilli"* (little stones) are merely fragments of rock broken still finer by being repeatedly ejected and again falling back into the crater, or being violently propelled against each other in the course of these ascents or descents.

Fig. 78. — VOLCANIC BOMBS.

It necessarily follows that the distance which these products of eruption lie from the mouth of the volcano is inversely to their size. Thus the great blocks and volcanic bombs, when they do not drop back into the crater, are usually found not far from the mouth; the lapilli, being lighter, are carried to a greater distance; while the dust and ashes may be borne on the wind for almost incredible distances. Tufa, a pasty rock, which often sets hard enough to be used for building purposes, is formed by the consolidation of the ashes, owing to the rain derived from the fall of the condensed steam, or the water which so often pours out of a volcano mingling with the volcanic dust. Occasionally, indeed (p. 137), it will form a brown-coloured substance, which, pouring down the sides of the cone, causes more mischief than all the primary products of the eruption put together. Ashes are sometimes the only ejecta of a volcano which is constantly in action. The island of Vulcano, in the Mediterranean, sends out stones and ashes, and sometimes ashes alone, though at one time it discharged all the usual products of a burning mountain. It seems by long friction to have so polished the funnel that there is little more to break off; and the lava having been exhausted, the explosions of steam or gas can find nothing more than the old ejecta to toss into the air once more, until in time some fresh disturbance may tap another reservoir of volcanic force.

* Or "rapilli," as they are locally known by the people living near Vesuvius.

Carriage of Ashes.—The distance to which a shower of ashes may be carried depends, of course, on the force of the wind at the time. If a stiff breeze happens to be blowing at the period of an eruption, it may happen that one side of a mountain will be less thickly covered than another more protected; and even in a comparative calm, the dense shower of ashes being shot up high into the air, often meets with a current which carries it far from the scene of volcanic disturbance. For example, in 1845 the dust from Hekla was, ten hours after it was propelled out of the crater, thickly deposited on the decks of vessels sailing along the Shetland and Orkney coasts. In 1835 the ashes from Coseguina, in Nicaragua, 700 miles distant, fell in the streets of Kingston, in Jamaica; and during the same eruption, the fine dust covered the ground 30 miles south of the volcano with a layer ten feet thick, destroying the woods and dwellings over a considerable area, and enveloping in its mass thousands of animals unable to escape before a fall so sudden. The ashes discharged out of Vesuvius in A.D. 512 dropped on the housetops of Constantinople and Tripoli; in 1815 dust from Sumbawa, estimated to amount to fully 185 mountains of the bulk of Vesuvius, fell, in common with stones, over an area of nearly one million square miles; and ashes from Sangay, in Ecuador, which discharges them in such quantity that it has buried the country round its base under a covering 4,000 feet thick, have been borne almost equally far. During the Icelandic eruption of 1874–75 large tracts of the adjoining country were covered with a thick blanket of ashes, and distinct traces of the shower were noticed as far away as the east coast of Sweden. During the eruption of Skaptar-Jökull, in Iceland, now more than a century ago, the fine dust ejected was in the atmosphere for months afterwards, and it fell in such quantities over Caithness-shire, more than 600 miles south of the volcano, that the crops were destroyed, and the tradition of this event still lives in the popular memory. It was also observed in Norway and Holland, so that the mere

fact of a layer of volcanic ashes, without more incontestable signs of the presence of an eruption close by, would not justify the geologist in saying that a volcano existed in the vicinity of such a stratum, for the facts mentioned would go far to prove that the materials of this layer might have been brought from a long distance.

These facts relate to volcanic dust. But from other data we know that fine powder can be wafted prodigious distances. Leaving out of account, as a little too vague for the important inferences to be derived from it, the assertion of Ehrenberg that in the brick-red dust collected from the decks of ships sailing near the Cape Verd Islands, he discovered South American diatoms, species of microscopic plants, covered with a flinty casing differently marked in different species, it is better established that sand from the Sahara has been detected in the Canary Islands, on the coast of Italy, and even as far as Lyons; while the Caspian steppes sometimes contribute part of their dusty soil to the snowy tracts in Southern Russia far to the west. But the most remarkable facts regarding the enormous distances which dust can be blown were furnished by the great eruption of Krakatau, in the straits of Sunda, on the 27th of August, 1883; and as the facts are especially connected with the theme of this section, they may be given at some length. This explosion was so violent that, according to official testimony, it was heard at a distance of 1,800 miles, and the puff of its air-wave injured dwellings two hundred miles distant. But it has been affirmed with some confidence that the air-wave started by this almost unprecedented eruption carried into the highest regions of the atmosphere and around the world matter which, for at least two years subsequently, affected the aspect of the sun in London and New York, and, it is said, influences it to this day. At all events, the extraordinary sunsets which were so marked a feature of the northern hemisphere for long after the date mentioned, were confidently attributed to the intervention of this invisible veil of Javanese volcanic dust between us and the luminary. No doubt, any substantial proof establishing the association of this Eastern catastrophe with those beautiful crimson sunsets and dawns, and the occasional blue suns and green moons, which were visible in London from the middle of November, 1883, has yet to be published, though an ingenious collection of statements and coincidences has been brought together in the endeavour to prove the case. However, astronomers of the eminence of Professor Langley have not hesitated to regard these sunrises and sunsets, and that dim reddish halo which coincidently made its appearance about the sun all the world over, as due to the dust and water vapour blown into the atmosphere. Most of the heavier particles of the showers of ashes and other *débris* ejected from Krakatau fell into the sea within a few miles. But a certain portion—the lightest—was probably carried by the explosion far above the lower reaches of the atmosphere, to descend so slowly that some of it may be still afloat. According to the official estimates made by the Dutch Commission employed to investigate the question, the amount which has not yet descended from the atmosphere, into which it was so violently projected, must be enormous. It would form a mountain in itself.*

Lava.—This is one of the most familiar accompaniments of volcanic discharges. It is melted rock which, on solidifying, forms a mass, varying in texture according to the materials out of which it was originally formed, the mode in which it was ejected, the amount of steam or gas passing through it, the speed with which it pours down the side of the volcano, and the slowness with which it cools. But though there are many varieties of it, lava has universally the same characteristics, and these characteristics (as we have seen) are those of the igneous rocks, of which basalt and the traps generally are the type. It also varies in the degree with which it is liquefied, some forms being denser than others, and therefore not flowing so far from the mouth of the crater

* "Comets and Meteors: the New Astronomy," in *The Century*, Jan., 1887, p. 342.

over which it pours. Frequently it goes only a short way before it solidifies. But in other instances it rolls in an ever-broadening stream down the mountain side, carrying everything before it, and scorching all vegetation with which it comes in contact. But in every instance the surface begins to solidify long before the interior of the lava river has hardened. Accordingly, as the surface cracks in cooling, the crawling stream bears along on its surface hosts of black blocks, hard or glutinous, until, as it nears the end of its course, it seems to the bystander no longer a liquid flow, but a confused stream of *débris* tumbling along by their own weight. Such an appearance was presented by the lava streams during the eruption of Etna in May, 1886. In the lava stream is also embedded a variety of foreign objects, most of which soon lose their individuality, being either burnt or fused by the intense heat of the molten rock.

All the time the lava is running it is discharging steam and other gases, so that Vogt has likened it to a locomotive engine, which has within itself substances both liquid and solid. The escape of this steam and the gases already noted (p. 140) gives the lava a more or less porous character, the density or porosity of the mass depending on the violence with which they escape, or the pressure under which the lava may have assumed the solid condition. The surface is also often slaggy or "ropy," when the current moves slowly, and therefore admits of the stream solidifying while the lava is being dragged along, or where little vapour of any sort finds its way through the liquid. In any case, the lava crawls slowly, a fact which is shown by the crystals formed in its mass or in the air-holes so characteristic of the resultant rock, whether of modern or of ancient date. When the lava stream is very broad and deep, what are called "slag fosses" are formed. These are seen to perfection at Thingvalla, or Allmannagjá, in Iceland, where considerable valleys have been formed by the subsidence of the centre of each lava stream. This depression has extended over an area of more than twelve and a half English miles, and to a depth of about 100 feet. In other cases lakes have formed in the hollows caused by these depressions in the lava field—Thingvallavatn, for example, which is a sheet of water about thirty miles in circumference, and in places more than 100 fathoms deep. In some instances we find heaps of slag which have accumulated at places in the course of a lava stream, from ten to twenty-five feet in height (Fig. 79). Indeed, so slowly do

Fig. 79.—SLAG DEPOSIT FROM A LAVA STREAM DISCHARGED BY VESUVIUS IN 1852.

lavas solidify that it is not uncommon for the surface to be firm enough to bear a man, while through the cracks the melted rock can be seen still glowing red, a few inches below the spot where the observer is standing. Eleven months after an eruption of Vesuvius the rock was so hot that a stick thrust into it caught fire, and though seven years after an eruption of Vesuvius, in 1785, lichens were growing on the surface of the lava streams, the interior was hot and steaming. It is even affirmed that the lava which flowed out of Etna in 1787 was steaming in 1830, and that eighty-seven years after the great eruption of Jurillo, in Mexico (p. 124), vapour could still be seen rising out of the cracks in its lava streams. This volcano rose up and was formed during a single night—the 29th of September, 1759—and there are Indians still living in Mexico who can remember old men who described the time when the spot where the mountain now rises to a height of 1,640 feet above the plain (4,315 feet above the sea level) was covered with palm-trees, sugar-canes,

and indigo. Eye-witnesses relate that from the summit of the mountain of Aguasarca, whither they had fled in terror at the first premonitory signs of internal throes, which consisted of earthquakes and in the atmosphere being laden with sulphuretted hydrogen, they beheld the earth over a space of more than half a square league "veritably take fire." Gigantic sheets of flame shot out of the ground, and immense numbers of red-hot stones were hurled to enormous heights, to fall earthward in showers of fiery hail. "The pliant crust of the earth rose like a convulsed sea above the ancient level of the plain, whilst above all hovered a dense cloud of cinders and scoriæ, brightly illuminated by the fires of the volcano struggling in its birth throes. The river San Pedro was shaken out of its bed, its waters being precipitated into the fiery chasm, where they became decomposed into their original chemical elements." The activity of the volcano continued unabated until the following February (1760), so that the present cone is entirely due to the *débris* ejected during the five months of its activity. Just before Leclercq and Fink ascended it, in 1883, various subterraneous rumblings had been heard, which the inhabitants fancied might presage another eruption, although the mountain had been dormant ever since its birth. Sudden subsidences are common along the floor of the crater, and in September, 1883, the mountain called El Cirate, near Quiroga, on the margin of Lake Pázcuaro, subsided nearly 150 feet. The tremblings of the earth are wont to make themselves felt, particularly on the approach of the rainy season, and columns of hot steam are at this period of the year frequently seen rising from the depths of the crater. When Humboldt visited the mountain forty-four years after its formation, the temperature of the "hornitos" (literally ovens), or miniature volcanic cones, emitting incessant columns of smoke, which emboss the plain and the mountain, was found to be 203° Fahr. The maximum heat at present is 152·6°. The floor of the crater is covered with an accumulation of lava blocks, and at one of the chasms at the bottom, through which steam ascends, the temperature was 152°.*

The temperature of the interior of a lava stream has never yet been accurately ascertained, though a copper wire $\frac{1}{30}$th of an inch in diameter melted when thrust into a Vesuvian lava stream, so that the heat must have been at least 2,204° Fahr., this being the point at which the metal in question fuses. Again, at places where it has overflowed houses in its path, the lava has been known to fuse the sharp edges of gun-flints and decompose brass into its components, while silver was not only melted, but sublimed into small eight-sided crystals. Limestone caught in the folds of a lava stream has been so completely metamorphosed that no trace of the original stratum has remained, while fresh minerals, such as wollastonite, augite, and black garnets, have been formed.

The slow rate of cooling of lava has been used as an argument to prove that if the centre of the earth was originally a molten mass, there is no ground for doubt that, covered as it is with a comparatively thin crust, its rate of cooling may have been so slow as to leave a large portion of it still in its pristine condition. A lava stream, after it solidifies, is usually slaggy at the top and bottom, and more or less homogeneous in the middle, though no certain rule prevails owing to the structure varying according to the circumstances which may obtain during the course and cooling of the current. Sometimes, indeed, especially if the stream has been shallow, or has met with many obstacles in its course, it is more or less cindery throughout; and when the air-bubbles contained in the mass are numerous, or the occluded steam has passed out rapidly, the surface will be so porous that a piece will float in water. This volcanic froth or scum is usually of a whitish-grey colour, and, under the name of *pumice*-stone,† is largely used as a polishing material. Very frequently the air-bubbles in lava show an elongated

* *Bulletin de la Société de Géographie de Paris* (3e Trimestre, 1886); *Scottish Geographical Magazine* (March, 1887).

† From the Italian *pomice*, froth.

form, the axis of the cavities being in the direction taken by the stream in which they

Lava, when rising to the surface, often bursts through fissures in the cone other than

Fig. 80.—CRATER OF VESUVIUS IN 1834.

are contained, or they run into each other so as to form what the anatomist would call a series of "anastomosing" veins (Fig. 81).

the crater, and sometimes even, when unable to reach the surface, solidifies in the form of those lava dykes seen in almost every

volcano, and which are identical with those which we have examined in the crust of the old earth (p. 100). The outbursts of lava appear to be due to the explosive force of the gas mingled among the molten rock. Sometimes, as in the Sandwich Islands, the lava will be propelled for days at a time from independent fountains, which throw it five hundred, and even a thousand, feet into the air; and in the same region—Mauna Loa, for example (Fig. 66)—the lava pours in a great river from various vents upwards of 10,000 feet below the top of that mountain, and 20 miles distant. Where the stream flows out of the crater—which it usually does in the smaller cones—it will sometimes by its force break down the sides of the basin (Fig. 64). When the stream first pours over the edge it is white-hot; then, as it cools, a red hue appears; and finally, throughout the greater portion of its course, it is of a dull black, as it creeps along at a rate depending, first, on its liquidity, secondly, on the steepness of the slope down which it rolls, and, thirdly, on the obstacles which it may encounter. But even after the surface had got encrusted, the great lava stream from Mauna Loa, in 1852, did not cease its progress for months, while at first it coursed along at the rate of seven and seven and a half miles an hour.

Fig. 81.—VERTICAL SECTION OF LAVA STREAM.

The size of these lava streams will, of course, vary according to the size of the volcano, or the amount of lava which it may discharge. Sometimes, the stream will solidify on the steep side of the cone, or even harden in the shape of a cascade, as it precipitates itself over a precipice, all the time expelling not only steam from its "fumaroles," as the points where the discharge is most marked are called, but other substances, such as sodium chloride (common salt) and iron, the one forming crystals and encrustations on the surface, and the other the yellow coating noticed round the edge of these vent-holes. In addition, various other gases make their appearance, and either get condensed on or about the lava streams, or, entering into combination with solids or vaporous objects in their vicinity, form some of the numerous products extractable from lava. They also ignite, and add to the weirdness of a volcanic discharge (p. 139). If a lava stream goes no farther than the vicinity of the crater (Fig. 80), or the base of the cone, it will only add to the area of the mountain, and slightly alter its contour. Vineyards and trees are still standing on the flanks of Vesuvius completely surrounded by the lava flood, which has not been able to reach the elevated oasis on which they stood; and in Hawaii clumps of forest are often seen in the middle of a lava-field. What is more, there is a dense layer of ice on Etna, which, having been overflowed by a sheet of lava, is thereby protected from the heat of the sun and evaporation, and so what the lava spared remains longer than it would have done, though, had the ice been thinner or situated in a less favourable position, or uncovered by a layer of earth, it would undoubtedly have been melted, and contributed to the flood which so often accompanies a volcanic outburst.

But if, as not unfrequently happens, the lava rolls far into the settled lowlands, and even into the sea beyond, the consequences are more important. Dams are formed across rivers, stemming back the current and flooding the neighbouring lands, until in course of time the stream can eat its way through the opposing obstacle (Fig. 54); or by the embankment a more or less permanent lake may be formed, and the navigation of the stream across which the lava has thrown itself be interrupted by a waterfall or a cataract. It may even happen that a valley may in a few days or weeks be filled with lava, so that a physical feature which it had taken ages for a river to sculpture will be completely effaced.

Hawaiian lava flows.—The size of some of these lava streams is enormous. Those which have so frequently flowed from the craters or calderas of Hawaii are shown in the map on p. 126. Lava is the chief eject of these island volcanoes, and is so thin—almost

like molten glass—that when the wind catches it up, it is drawn into slender filaments, which go by the name of "Pele's Hair," Pele having been, in the old Hawaiian mythology, the goddess who presided over the action of these fire fountains, and had her seat in the crater. Some of these are of prodigious extent; for instance, that of 1852, which proceeded from an eruption of Mauna Loa, formed an unbroken fountain of lava 200 to 700 feet high and 1,000 feet broad, though it did not burst out of the crater, but from the base of the cone. The crater of Kilauea is situated on the flank of Mauna Loa, at a height of 4,200 feet, while that of Mokuaweoweo lies in a deep pit in the actual summit, 9,500 feet higher. Kilauea is always moderately active, but keeps so circumspectly within the limits of its own huge caldera (p. 125) that it rarely does any damage, and is one of the show-places of the island of Hawaii (Fig. 82). But Mokuaweoweo is a crater of a very different character. When the internal furnace is so thoroughly heated as to force a torrent of lava to that height, the molten current begins to overflow the walls of the basin, burns its way through the forests, and perhaps overwhelms cultivated sugar-fields and villages on the mountain slopes, or even in the valleys adjoining the sea. Then comes a time of awful anxiety as to the probable force of the flood as it sweeps onward by devious paths, pouring in cascades of fiery red fluid rock, and travelling from thirty to sixty miles ere it ends its course in the sea, raising a wild commotion among the great waves, which break unceasingly on these lava-bound shores, the clouds of spray which scud from their crests being tossed skyward by the huge volumes of steam which rise from the boiling waters.

The first eruption of which we have a distinct record occurred in 1789. It was accompanied by fearful earthquakes, dense darkness, and terrific thunder and lightning. An island war was raging at the time, and a body of men marching from Hilo to Kau were encamped by the volcano where the outburst began. Terrified, they halted for two days, and on the third divided into three companies and started at short intervals. Of the foremost company some were burnt to death by sand and cinders, thrown to an immense height, and overwhelming them. The third body escaped almost uninjured, but on coming up with the centre party they found only corpses of men, women, and children. Contrary to the rule, the eruption seems to have consisted solely of sand and scoriæ, with volumes of steam and sulphurous vapour.* In 1823 the lava stream was thirty miles long. In 1840 the bed of the crater of Kilauea sank about 300 feet, and her fires vanished underground "with roaring and much commotion, till they broke open a passage in the district of Puna, whence they rolled onward, burning forests, villages, and plantations —a terrific flood, from one to three miles wide and from 12 to 200 feet in depth, varying with the extreme irregularity of the ground, and having travelled a distance of 30 miles in four days, it entered the sea 17½ miles from Hilo, leaping a basaltic precipice about 50 feet in height, and forming a magnificent fire-cataract a mile in width." All the time the surface was so clouded in steam and smoke that those standing on one side of the lava river could not see to the other shore. Sometimes this "Mississippi of molten material" widened like a great lake, then narrowed as it "rushed through deep valleys, finally leaping into the sea in a cataract like Niagara, in a raging blood-red torrent." For three weeks, we are told, the flow continued. The sea boiled and raged madly as the torrent mingled with its waters. For twenty miles along the coast the waves were warm, and myriads of dead fishes floated on the waves. So intense was the glare that at places forty miles distant a "fine print could be read all night by its lurid glow, and ships a hundred miles at sea beheld the strange light."

In 1843 Mauna Loa broke out near the

* Miss Gordon-Cumming: "Fire Fountains," 2 vols. (1883), in which will be found an excellent account of those volcanoes from which many particulars have been gleaned. In Captain Dutton's Memoir (U.S. Geological Survey, 1882–3), and Mr. Brigham's treatise on the same subject (*Memoirs of the Boston Society of Natural History*, 1868–9), the scientific questions involved are discussed still more fully.

summit, and discharged, through two new craters, two streams of lava, one of which flowed towards Kona and the other towards Mauna Kea, when it divided into two currents. Dr. Coan describes the evening when the stream began to run as clear and quiet. "But as the sun disappeared a strange light was noticed upon the summit of Mauna Loa. A clear, white flame, whiter than the moon, deeper and stronger than any star, rested upon that distant crest, and grew momentarily more vivid as we gazed upon it. The mountain was really aflame; no fitful jets of fire or whiffs of heated stones, as in other volcanoes, but a steady column of white-hot lava, playing noiselessly in the still night, yet emitting a light so powerful that we could read by the fiery splendour that cast strong shadows against the moonlight." Again, in 1855, not to mention others of less note, though of sufficient grandeur to dwarf anything of the kind in Europe, there occurred the most awful eruption on record. It began near the summit of Mauna Loa, and flowed from nearly 14,000 feet in lineal height down the slopes of the mountain in a stream of such volume that the town and harbour of Hilo was threatened. In places it was three miles wide, and where more level ground was reached the flood widened into a lake of from five to eight miles in diameter. Then parting, it divided into a network of rivers, which burnt their way through the forest and leapt precipices in a succession of cataracts and rapids. The rivers became so impregnated with pyro-ligneous acid, draining from the vast tracts of burnt forest, that many of the streams, and even the Wailuku River, assumed a hue as black as that of ink, and so offensive a taste and smell that for a time the water could not be used for domestic purposes. For six months the lava flow continued, and at one time, when it approached within six miles of the town, it seemed that nothing could save the place from being overwhelmed. But though the eruption continued for twelve months more, the lava stream was diverted and the town saved. The course of this river was sixty miles in length, and covered nearly 300 square miles of land with millions of tons of lava. At one point the velocity of the current was estimated at forty miles an hour, and so pasty was the lava that it flowed continuously at angles varying from one to ninety degrees, and in places clung to the inward curves of rock, until it formed a thin glaze over the surface. In 1859 another eruption sent, in eight days, a lava river sixty miles long into the sea at Wainanali, leaping in its way precipices thirty feet in height, and shooting up jets and columns of ignited gas and fiery matter to the height of 30, 50, and 60 feet. Smaller eruptions occurred at intervals in the succeeding years, Kilauea being generally in sympathetic action with the summit crater, though it is extremely rare that the boiling lava sea in that lake-like crater ever overflows its extensive bounds, though jets of steam and spouting lava through fissures forty miles distant show in what direction the seemingly dormant volcano is working.

Towards the end of March, 1868, over a thousand shocks of earthquake were felt in five days, and on the 2nd of April the entire country was convulsed by one the like of which has not since been known. On the day mentioned a torrent of mud, half a mile wide and about twenty feet deep, burst from the mountain side and rushed down with such velocity that in a few minutes it had overwhelmed ten houses, buried thirty-one men, women, and children, and many hundred head of cattle and flocks of goats, not one of which has ever been disinterred. Most probably the mud stream was, like some of those described in previous pages, due to the volcanic disturbances having broken open some interior reservoir of water, and giving access to the lava stream, generated so much steam as to blow open the side of the mountain from which the muddy river obtained exit.

The lava stream seems, at all events, to have flowed under the soil, for it burst forth at intervals in the shape of spouts through fissures. One of these fissures, thirteen miles in length, continues steaming to this day. Finally, after four days, it burst forth at a height of 3,800 feet above the sea, pouring forth four streams through a fissure nearly a

mile long. These fountains boiled with great fury, throwing up columns of crimson lava and red-hot rocks to a height of 500 or 600 feet, and then falling in a flood which, after pouring over a precipice 500 feet high, reached the sea in two parallel streams, not without overwhelming on the way many houses and destroying more than a hundred people. Within an island formed by the parallel streams thirty head of cattle were imprisoned for ten days,

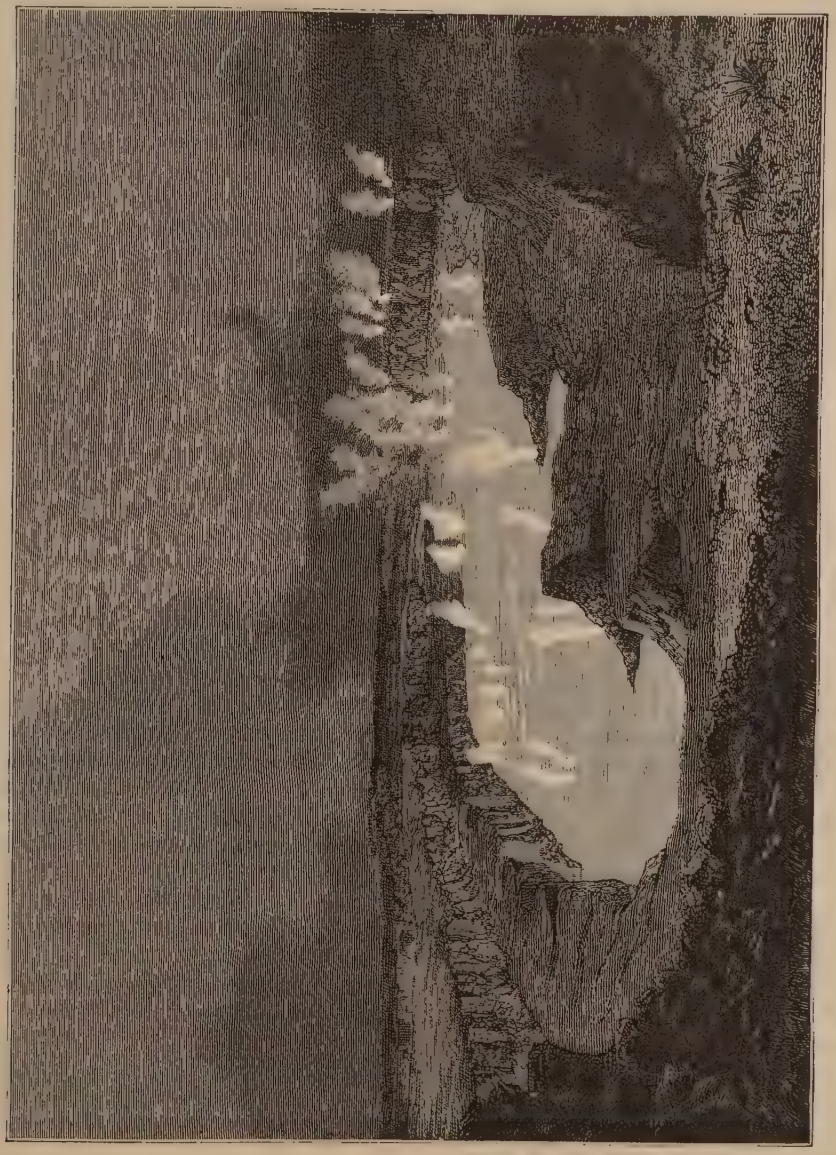


Fig. 82.—LAVA LAKE IN THE CALDERA OF KILAUEA.

till they were maddened with the heat, thirst, smoke, and dust of their fiery fences.

On the 14th of February, 1877, there was an eruption of six hours, after which the lava stream flowed underground until it appeared at a distance of fifty miles, where it caused a submarine eruption in Kealakeakua Bay, famous as the spot where Captain Cook was killed. In November, 1880, the fire fountains again played, some forming three cones, one of them 400 feet in height, and sending a lava stream downwards until, in the plateau between Mauna Kea and Mauna Loa, it formed a lake of tossing and raging fire, several miles in diameter, and varying in depth from 10 to 300 feet. From this reservoir three streams started in different directions towards the sea. These re-divided in the course of their flow, making, however, directly for Hilo. Many of the inhabitants removed everything, and waited with anxiety for the end. But though all danger was not over for more than nine months, the oft-threatened town again escaped the fate which seemed at one time inevitable.* In the early part of the year 1886 the fires of Kilauea suddenly subsided; the great caldera, for the first time in the brief history of the Sandwich Islands, showed no sign of activity. People descended into the bed and peeped down the chimneys through which the lava used to well into the forsaken "lake of fire," and when a new volcanic island rose in the Pacific not far from Tonga, and the dormant volcanoes of New Zealand broke out afresh, there were not lacking theorists to affirm that at least the volcanoes of the Hawaiian group had become extinct, or at least had begun to take a long holiday in favour of their less active brethren farther south (Fig. 76).

How idle were such surmises was proved by symptoms of activity again displaying themselves in Kilauea, and on the 16th of January, 1887, after violent earthquake shocks, which continued for several days almost without interruption, Mauna Loa, which had been silent since the great outburst of 1881, just described, broke forth in a lava stream, which coursed down the south-west side of the mountain, entering the sea two miles north of that of 1868, though the fissure from which it flows is twelve miles farther up the mountain, or twenty-one miles from the ocean. As usual, it was preceded by a sharp jet of lava shooting up to an immense height from the Mokuaweoweo caldera, at the summit of the mountain, though the actual flow did not begin till the 18th, more than half-way down the south-western flank of the cone. It was extremely copious, rising in several large fountains, from 100 to 200 feet high, and reached the sea in 26 hours in a current averaging about three-fourths of a mile in breadth, leaving behind it a hideous embankment of clinkers, through the fissures in which, for several days subsequently, the fiery interior was disclosed. No cinder cones (Fig. 79) have been formed by contact with the sea on this occasion, but Mr. Bishop, who visited the spot a fortnight after the flow had ceased, notes that six or seven cones stood in the vicinity, one having risen out of the sea at the flow of 1868, and been immediately united by lava to the land. This new flow consists almost exclusively of the coarse lava known in Hawaii as *a-a;* the neighbouring flow of 1868, equally sudden and captious, being *pahoehoe*, or the smooth variety.† The new flow seems also to abound in the mineral called olivine. Experienced observers at Hilo, however, are of opinion that this is only a temporary intermission, and that activity will speedily be resumed, with probably a "pahoehoe" flow, such having been the general history of great eruptions, like those of 1881 and 1855.

Mr. Bishop notes that the course of the lava stream could be easily traced by a heavy,

* "Fire Fountains," Vol. I., pp. 125–209, and Vol. II., pp. 235–78.

† In the Sandwich Islands the different lavas are known under the native names of (1), *a-a*, spongy, coarse, and hard, which on account of its extreme roughness is avoided by pedestrians; in the holes of this lava the Hawaiians plant banana shoots or sweet potato cuttings, and in spite of the "soil" being simply stones or fern leaves the plants flourish; (2), *pahoehoe*, or velvety lava, is the form taken when the stream has passed over a gentle slope. The clinkers, or scoriaceous lava, are found where the stream has passed through woods, or met with other obstacles which have impeded its progress.

stationary line of dark cloud hanging precisely over it. Although a little puffing of steam was rising out of the sea, nothing but dry heat ascended from any point inland, save two small columns of sulphurous smoke four miles up. In walking along the lava flow, currents of highly-heated air had to be avoided, but no steam was observed, nor smoke, nor fumes of any sort which could be detected by the senses. Yet a dense, massive, condensation of vapour was constantly going on directly overhead, which vapour was most probably due to the inflowing currents of air charged with their ordinary amount of moisture. "They were drawn in and driven up from the immense heated surface, and on reaching the necessary height, precipitated their contents into the dark cloud-bank just as naturally as the sea breeze piles its clouds daily against the mountain flank all along that coast." This shows that the presence of clouds above a lava stream is no proof of steam rising from it. It may be added that the latest eruption of Mauna Loa was first announced to the Honolulu people by the pervading smoke continuing from the 20th to the 30th of January. This smoke is evidently first discharged into the upper current of the air, and transported far to the east-north-east before settling down into the trade-wind, which brings it back to the island of Oahu, on which the capital of the group is built.†

CHAPTER VIII.

Volcanoes: Amount of Ejecta; Volcanic Islands; the Unstable Earth.

Amount of Material Discharged from Volcanoes—Examples from Hawaii, Iceland, Etna, and Java—Krakatau Eruption—Submarine Eruptions—Islands Resulting from them—Examples from Iceland, the Azores, the Mediterranean, and the Pacific—The Earth rarely at Rest—Either Slowly Rising or Slowly Sinking—Examples of this Imperceptible Secular Rise and Fall—Cause—Cause of Volcanic Action.

It will be seen from the foregoing facts that the amount of lava which volcanoes like those of the Sandwich Islands—immense in bulk, violent in action, and copious in the discharge of what is almost their only product of eruption—emit must be prodigious. Mauna Loa, it is no exaggeration to say, is "the king of volcanoes," for no other in the world approaches it either in bulk or in activity. As Captain Dutton very justly claims for the mountain, the scientific history of which he has done so much to elucidate, it is, if not so lofty as some of its kindred, actually more striking; for while they usually stand on elevated platforms, where they appear as cones of greater or less size, Mauna Loa is so near the sea level* as to gain little by any adventitious circumstances of the kind mentioned. Etna, with all its adjuncts, is inferior; while Shasta, Hood, and Rainier (Tacoma), in North-West America, if they were melted down and run together, would fall much below the volume of the island volcano. The magnitude of Mauna Loa is due chiefly to the great area of its elliptical base, which has a major diameter of 75 miles, and a minor of 53, measured at sea level.

Amount of Ejecta.

In its aggregate eruptions, Mauna Loa is also unequalled. No doubt some of the Iceland volcanoes have been known to disgorge

* In reality, it is probably far below it, though, on the other hand, it may not be so low as the adjoining depths of the Pacific, for there is evidence to show that its platform, since it first rose out of the sea, has been "hoisted" to a considerable extent during the progress of its eruptions.

† Bishop: *Science*, Vol. IX., No. 213, pp. 205–207; Hitchcock: *Ibid.*, No. 212, pp. 180–85; *St. James's Gazette*, Feb. 22nd, 1887.

at a single outburst an amount of lava fully equal to them. For instance, in 1783 Skaptar-Jökull ejected successive lava streams of such magnitude that they filled up valleys and river gorges 600 feet deep and 200 feet broad, and covered with sheets of molten rock 100 feet thick, plains 12 to 15 miles wide. Two of the lava streams nearly equalled the greatest of those from Mauna Loa, for they were respectively 50 and 40 miles long and 100 feet deep. It has, indeed, been estimated that the total lava vomited forth during that eruption alone would exceed, if piled up in a solid mass, the bulk of Mont Blanc, while the flow covered altogether an area of 420 square miles. This eruption was the cause by which, directly and indirectly, 20 villages, one-sixth (over 9,000 people) of the inhabitants of the island and one-half of the live stock were destroyed. The Icelandic volcanoes, however, are more noted in recent times for the ashes and sand they disgorge than for their lava flows. Hekla (Fig. 83), which, like most volcanoes (p. 120), varies in height after each eruption,* gives forth so much ash that the earliest historical eruption, that of 1104, is celebrated as the "sand-rain winter;" the second, in 1158, as "the great darkness," from the air being obscured by the dust floating about in it. In 1766 a column of ashes was seen to rise out of Hekla to the height of 16,000 feet; and though the other volcanic vents are better known for their emissions of lava, they have also always been as locally noted for the ashes discharged, as those of the Sandwich Islands are for the lava which forms almost their only contribution to the upper world. But while in Iceland lava eruptions are unfrequent—more than a century having elapsed since any of much importance has occurred—those of Mauna Loa are all of great magnitude, and occur irregularly, with an average interval of about eight years. Taking the total quantity of material disgorged during the past century no other volcano is comparable to it. Captain Dutton considers that a moderate eruption of Mauna Loa represents more material than Vesuvius has emitted since the days of Pompeii, and that the great flow of 1855 would have nearly built Vesuvius, while those of 1859 and 1881 were not greatly inferior. Yet both Mauna Loa and Kilauea are in many important respects abnormal. Their eruptions are singularly quiet. In only one or two instances within the historic period have they been heralded by any such portents as earthquakes or subterranean rumblings; and the vast jets of steam blown miles high, hurling stones, cinders, and lapilli far and wide, filling the heavens with vapour and smoke, and hailing down fragments and ashes over the surrounding region, have never been observed here, or only in a very feeble way. People stand to windward of the welling lava, without feeling inconvenience save that their faces tingle with the heat. Ordinarily the outbreak takes place without warning, the first intimation the islanders have of the eruption being the sky aglow and the fire fountains playing in the darkness. As the news spreads, hundreds of people flock to witness the sublime spectacle, and display about as much eagerness to approach near the scene of action as the inhabitants of other countries show to get away from so dangerous a neighbourhood. Hence, the *débris* which serves to build up the acute cones of most other volcanoes being absent, the Hawaiian mountains are without any summit cone, their tops being, as we have seen (p. 126), mainly "broad flat tables with immense pits sunk in them."† Etna, however, has a tolerably vehement discharge of lava. In 1865, it has been computed by Von Waltershausen,‡ that over 92,000,000 cubic yards of lava flowed out of Etna; and in 1852 the amount was fully four and a half times as much. In 1669 the most terrible flow on record occurred, in which, not including the mischief caused by the showers of ashes and

* Before that of 1845 it was usually put down at 4,951 feet, but in 1850 Kjerulf found it to be only 4,532 feet, though probably the difference may to some extent be due to errors on the part of the surveyors.

† Dutton: *Report of U.S. Geological Survey* (1882—83), pp. 84, 85.

‡ "Der Aetna," Vol. II., p. 393.

Fig. 83.—CRATER OF MOUNT HEKLA.

stones, which covered the country for a distance of sixty miles from the mountain, the lava destroyed Belpasso, Mascalucia, San Pietro, Camporotondo, Misterbianco, and fourteen villages. The quantity of lava was reckoned at more than ten times the amount in 1865; while even that prodigious flow is believed to have been exceeded by the torrent of which the evidences exist near Randazzo. The history of this flow, however, is unknown to us. That of 1669 is better recorded, for, apart from the damage done to the towns and villages mentioned, it undermined a hill at Albanello, two miles from Catania, and carried it and its corn-fields and vineyards forwards for a considerable distance. A vineyard, it is said by Alfonso Borelli, professor of mathematics in Catania, who, as an eye-witness, has left us so full an account of this great catastrophe, was seen floating on the surface of the burning river. Under the walls of Catania the lava current stayed its progress until it accumulated level with the summit—60 feet—and then, pouring over in a fiery cataract, overwhelmed several of the streets, and flowed on to the sea, which it entered in a stream 1,800 feet broad and 40 feet deep. The length of the river, which approaches in magnitude closely to those of Hawaii, is given at 15 miles, with an average breadth of between 2 and 3 miles, so that it covered 40 square miles of surface. For the first twenty days of its flow it progressed at the rate of 13 miles a day. But as the lava began to solidify, its current was so much slower that during the last three weeks of its course it did not move at one-sixth of that speed.

The thin flowing lava which, in 1794, destroyed Torre del Greco extended for upwards of 16½ English miles, and was nearly 4 broad at the place where it fell into the sea. The eruption from Val de Bove, in 1852–53, lasted more than nine months, and produced a lava stream less than two English miles in breadth, and 6⅕ miles long. In September, 1852, this sea of fire had filled an entire valley, though the eruption did not abate until May of the following year. During the terrible eruption of 1772, in Java, Papandayang, a cone 9,000 feet high, discharged in a single night *débris* reckoned to amount to 30,000,000,000 cubic feet. It fell on the country around to the depth of 50 feet, and buried under its load 40 villages and about 3,000 human beings. After the eruption the volcano was found to have shortened itself by 4,000 feet, and to have formed a vast crater, or more probably a caldera lake, whence the ejecta had been disgorged. In the island of Timor, a volcano, visible at a distance of 300 miles at sea, is said to have entirely disappeared. Galung-gung, on the 8th October, 1822, suddenly burst into eruption, and in a few moments the landscape, which had previously been suffused with the brightness of a tropical sun, was shrouded in the darkness of night. Over a radius of nearly 20 miles everything was destroyed by the deluge of hot water and mud (p. 38) which poured down the mountain sides. Four days afterwards a second eruption, accompanied by an earthquake, broke down the summit of the mountain, and converted one side covered with forest into a semi-circular gulf. New hills and valleys are said to have been formed, and rivers had their courses changed. Upwards of 4,000 people were killed and 114 villages destroyed, though no previous eruption of the mountain was on record. In 1843 Guntur, in the same island, flung out ashes and sand estimated to weigh 20,000,000 tons. During the still more tremendous eruption of Tomboro, in the island of Sumbawa, the sound of the explosion was heard as far away as Sumatra, 970 miles distant; and in the Gresca district, 300 miles away, the fall of ashes caused utter darkness. A resident in the district entered in his diary on the 12th of April, 1815, these words:—"11 a.m.—Breakfasted by candle-light; the birds began to chirrup as at the approach of day." Out of 12,000 people in the vicinity of the volcano only 100 escaped, while the survivors regarded the catastrophe as indicative of some great event pending or happening. "It heralded the re-establishment of the former government" (the Dutch), or "it was a retribution for the murder of a Rajah by his brother;"

while others accounted for it by a reference to their legendary tales, saying that "Nyai Loroh Kidal had been marrying one of her children," the ashes being the dregs of the ammunition she had used in firing salutes from her subterranean artillery.

Krakatau.—But of all the volcanic disturbances of modern times, that of Krakatau, or Krakatoa, in the Strait of Sunda, between Sumatra and Java, was the most widespread. We have already more than once referred to it, since it forms a typical example of almost every catastrophe which can follow the earthquake and the volcano. Its greatest activity began on the 27th of August, 1883, and apart from the destruction caused by the ashes and stones—some of which fell 250 miles east of their source—a great tidal wave, rushing in on the west and north-west coast of Java, choked up rivers, overflowed land, and swept away many villages and even considerable towns, besides lighthouses and other public works. The disturbances originated on the island of Krakatau with eruptions of red-hot stones and ashes, and by noon next day Semeru, the largest of the Javanese volcanoes, was reported to be belching forth flames at an alarming rate. The eruption soon spread to Gunung Guntur and other mountains, until more than a third of the forty-five craters of Java were either in activity or seriously threatening it.

Just before dusk a great cloud hung over Gunung Guntur, and the crater of the volcano began to emit enormous streams of white sulphurous mud and lava, which were rapidly succeeded by explosions, followed by tremendous showers of cinders and enormous fragments of rock, which were hurled high into the air and scattered in all directions, carrying death and destruction with them. The overhanging clouds were, moreover, so charged with electricity (p. 144) that water-spouts added to the horror of the scene. The eruption continued for all the Saturday night, and next day a dense cloud shot with lurid red gathered over the Kendang range, intimating that an eruption had broken out there. This proved to be the case, for soon after streams of lava poured down the mountain sides into the valleys, sweeping everything before them. About two o'clock on Monday morning—we are drawing on the account of an eye-witness—the great cloud suddenly broke into small sections and vanished. When light came it was seen that an enormous tract of land, extending from Point Capucin, on the south, to Negery Passoerang, on the north and west, to the lowest point, covering about fifty square miles, had been temporarily submerged by the "tidal wave." Here were situated the villages of Negery and Negery Babawang. Few of the inhabitants of these places escaped death. This section of the island was less densely populated than the other portions, and the loss of life was comparatively small, although it must have aggregated several thousands. The waters of Welcome Bay in the Sunda Straits, and Pepper Bay on the east, and the Indian Ocean on the south, had rushed in and formed a sea of turbulent wave. On Monday night the volcano of Papandayang (p. 158) was in an active state of paroxysmal eruption, accompanied by detonations which are said to have been heard for many miles away. In Sumatra three distinct columns of flame were seen to rise from a mountain to a vast height, and its whole surface was soon covered with fiery lava streams, which spread to great distances on all sides. Stones fell for miles around, and black fragmentary matter carried into the air caused total darkness. A whirlwind accompanied the eruption, by which house-roofs, trees, men, and horses were swept into the air. The quantity of ashes ejected was such as to cover the ground and the roofs of the houses at Denamo to the depth of several inches. Suddenly the scene changed. At first it was reported that Papandayang had been split into seven distinct peaks. This proved untrue: but in the open seams formed could be seen great balls of molten matter. From the fissures poured forth clouds of steam and black lava, which, flowing in steady streams, ran slowly down the mountain sides, forming beds 200 or 300 feet in extent. At the entrance to Batavia was a large group of

houses extending along the shore, and occupied by Chinamen. This portion of the city was entirely destroyed, and not many of the Chinese who lived on the swampy plains managed to save their lives. They stuck to their homes till the waves came and washed them away, fearing torrents of flame and lava more than torrents of water. Of the 3,500 Europeans and Americans in Batavia—which for several hours was in darkness owing to the fall of ashes—800 perished at Anjer. The European and American quarter was first overwhelmed by rocks, mud, and lava from the crater, and then the waters came up and swallowed the ruins, leaving nothing to mark the site, and causing the loss of about 200 lives of the inhabitants and those who sought refuge there. "Bantam was entirely covered by water, and 1,200 to 1,500 are believed to have been drowned. The island of Serang was completely inundated, and not a soul survived. At Cheribon there was no great flood of water, but the loss of life and property by falling rocks and lava must have been considerable. Buitenzorg suffered seriously, as did Samarang, Djokjo-Kerta, Sourakerta, and Sourabaya. The numerous temples at Brambanan were greatly damaged, and some of them destroyed. The dome of the noted temple of Borobodo was crushed in by falling rocks. The town of Tamerang was swept away by the flood, and fully half the population, mostly Javanese, numbering about 1,800, perished. At Speezwyk red-hot stones set fire to the houses and swept away all the thickly-settled portions of the town. About ten bazaars belonging to Europeans were destroyed. The river Jacatra, on the banks of which Batavia is situated, was so completely dammed by lava and *débris*, that its course was changed, and from Franien Bastion it flowed down through Tjgers Street and joined the waters of the river Emerades, swelling that stream to such an extent that it rose high on the Castor batteries. Figeleking was almost totally destroyed, and a large number of lives lost. The island of Onius, five miles off, at the mouth of the Tangerang river, and twenty miles east of Batavia, was completely inundated and the floating dock totally destroyed. Baby and Cheribon islands lost a few houses and inhabitants upon them. In Batavia the roof of the governor's house was crushed in by a mass of mud, and three servants were killed. Midah Island, ten miles off, on the coast of Java, was almost wholly engulfed." The towns of Anjer, Tjiringin, and Telokbetong, were either partly or wholly destroyed. Merak, three miles from Krakatau, was effaced; and many of the lighthouses along the Sunda Strait either disappeared or were rendered useless. The aspect of the Strait was much changed, and the navigation for a time dangerous. Some 900 inhabitants of the town of Waronge were known to have been killed, and at Talatoa, on the coast, 300 bodies were found. From all over the island came reports of loss of life and property, and it was at one time thought that the estimate of 75,000 would not prove excessive. On the lowlands of Batavia, when the waters receded, hundreds of bruised and mangled bodies lay exposed. The graphic account from which these notes are condensed was transmitted immediately after the catastrophe, and though checked by more recent reports, may, perhaps, have been exaggerated in some particulars, especially as regards the loss of life. But in its essential details it is sufficiently accurate to be of scientific value, while it notices almost every phenomenon attending a volcanic outburst and a great earthquake shock.

It will be seen that the eruptions began in the island of Krakatau, in the Sunda Strait, on which is a volcano which has been frequently active, and several weeks before the great outburst exhibited symptoms of uneasiness. At first it was reported that Krakatau had entirely vanished. But a considerable portion of it still remains, though, in places where land formerly existed, soundings of 160 fathoms have been taken without bottom being reached. A large portion of the erupted matter seems to have been deposited a few miles to the north of Krakatau, where, in addition to smaller land specks, two new islands, Steers and Calmeyer,

GLACIERS OF THE SIND VALLEY IN THE HIMALAYAS. (KASHMIR)

made their appearance, and formed the shoals to the north of Lang Island, which seems to have been about on the line between the upheaval and downfall, and has not materially changed in size. All of the islands were covered with ashes, as were the trees and hills in the vicinity of St. Nicholas Point, while vessels navigating near the site of the eruption had their decks covered with ashes 18 inches deep, and passed through masses of floating pumice-stone seven feet thick. This so-called "tidal wave"—about which we shall say something when discussing earthquakes—however, wrought more destruction than the volcanic discharge. The regurgitation of the sea having caused the waters to rush through the valleys of Thwart-way Island, clearing away the vegetation, and leaving the lowland bare, gave these breaks in the forest the appearance from a distance of five islands. There was, however, no change in the soundings either here or at Anjer; but the base of the lighthouse at Fourth Point and the buoys of the submarine cable were the only monuments which remained of that once populous town. The plains were swept by the sea, and showed, after the hurly-burly was over, only uprooted palms and ghastly relics of the inhabitants. Prior to the eruption of Krakatau, Verlaten and Lang Islands were covered with verdure. Their contour changed very little after that event, though they were covered with scoriæ. A small island formed eastward from Verlaten.

Fig. 84.—VOLCANO IN AMSTERDAM ISLAND, SOUTH INDIAN OCEAN.

The Polish Hat disappeared, and where it stood the lead-line showed twenty fathoms of water. A new rock, about 20 feet in height, rose in eight fathoms near the south end of Lang Island, while various reefs and islets appeared in the channel south from Sebesi Island, in addition to the two large islands mentioned as having arisen in another portion of the strait.

The distance to which the ashes were carried has already been noticed (p. 145). They showed much the same composition as those from the volcanoes of the Cascade Range in North-West America.* The pumice-stone reached the harbour of St. Paul on the 22nd of March, 1884, after having made a voyage of some two hundred and six days at a rate of six-tenths of a mile an hour. Immense quantities of pumice of a similar description, and believed to have been derived from the same source, reached Tamatave in Madagascar five months later, and no doubt much of it is still floating round the world. Another result of the eruption was the series of atmospheric waves, caused by the disturbance in the atmosphere, which affected the barometer over the entire world. The velocity with which these waves travelled has been variously estimated at from 912·09 feet to 1066·29 feet per second.† This speed is of course very much inferior to that at which sound travels through the air. Yet, in three distinct cases, the noise of the Krakatau explosions was plainly heard at a distance of at least 2,200 miles, and in one instance—that recorded from Rodriguez—of nearly 3,000. The sound travelled to Ceylon, Burmah, Manila, New Guinea, and Western Australia, places, however, within a radius of about two thousand miles; but Diego Garcia is without that circle, and Rodriguez, a thousand miles beyond it.‡ Six days subsequent to the explosion, after the atmospheric waves had travelled four times round the globe, the barometer was still affected by them, though, until the official and other reports, not yet complete, are published, accurate data regarding the most remarkable of the many volcanic eruptions of Java and the neighbouring country will still be lacking.§

Krakatau illustrates the violence with which not only the slow accumulated results of time can be destroyed, but the rapidity with which such a geological agent can heap up the *débris* in another place. A cone may take ages to grow, or it may appear like Monte Nuovo—a volcanic hill near Naples, 456 feet high—which was upheaved on the 30th of September, 1538. In 1872, when Vesuvius was in violent eruption, it discharged rocks nearly four miles into the air, and such an amount of lava poured through the great fissures on every side, that Palmieri describes the mountain as "sweating fire."

Finally, as proving what powerful factors volcanoes are in re-assorting the materials of the earth's crust, and how fully equal they are to the task of forming the loftiest trap hill in the world, we may devote a few lines to the vast "lava beds" which in Idaho, Washington Territory, Oregon, Nevada, and Northern California, extend over an area of at least 200,000 or 300,000 square miles,‖ in the

* Iddings: "Notes on the Volcanoes of Northern California, Oregon, and Washington Territory." (*American Journal of Science*, September, 1883.)

† Le Conte: *Science*, Vol. III., No. 71, p. 702; Boutelle: *Ibid.*, p. 776.

‡ Paul: *Science*, Vol. IV., No. 80, p. 135.

§ The literature of the subject is already getting extensive. Our account is derived from private correspondence, a collation of the various reports in the scientific journals, and of eye-witnesses, published in the newspapers of the day. Dr. Verbeek has issued a special work on the subject ("Kort verslag over de uitbarsting van Krakatau op 26, 27, en 28 Augustus' Batavia, 1884), which with his "Topographische en geologische beschrijving van een gedeelte van Sumatra's westkust" (Batavia, 1883), and "Topographische en geologische beschrijving van Zuid-Sumatra" (1881), and the standard works of Junghuhn and Veth, will afford all the information necessary regarding Java and its volcanoes. The Royal Society is preparing an exhaustive report on the subject, which will, no doubt, contain a carefully-sifted digest of all that is known regarding the eruptions, the earthquakes, and the tidal waves.

‖ Le Conte: *American Journal of Science*, 3rd ser., Vol. VII. (1874), p. 168; Russell: *United States Geological Survey*, 1882-83, p. 451; Arch. Geikie: "Geological Sketches," p. 278. The writer also has visited them.

regions between the Sierra Nevada and Cascades, and the Rocky Mountains. These vast sheets cover the country like a flood, here and there taking the columnar form, like the older basalts (Fig. 86), albeit the origin of these lava beds is, geologically, comparatively recent.* Viewed a few miles from its edge this huge mass seems to stretch illimitably. Yet no volcanic cone can be detected, and there is no reason for believing that, as in Auvergne, the action of the wind and the weather has effaced the volcano which disgorged this flood of molten rock. But from what we have seen of the Hawaiian and other volcanic vents, there need be little hesitation in accepting the suggestion (made first in print by Von Richthofen in 1868, though this idea had presented itself to more than one traveller over this tract long before the famous German geologist visited it) that a cone and a crater were not necessary, the lava having simply been spewed out through great fissures in the ground (Fig. 85). This explanation may also apply to other basaltic plateaux and sheets, such as those in the West of Scotland, in Antrim in Ireland, in Abyssinia, Western India, and Victoria, in the vicinity of none of which has any cone or crater been discovered. (Fig. 86).

One lava flow overlies another almost like one stratified bed over those below it, so that on making a section of any deposit, the slightest flow may be detected, each stream having usually something to distinguish it from its predecessors. (Fig. 81).

Submarine Volcanoes.

Hitherto we have only been considering volcanic action as manifested on land. But there is no reason why there should not be volcanic eruptions under the sea, or indeed under any water. Indeed, in some respects there is some ground for believing that they should be more active in such localities; for if the water infiltrating through the cracks in the earth's crust, and coming in contact with the molten matter or internal fires, has a leading part in causing the explosions to which eruptions are due, the leaky bottom of the ocean and other places constantly covered by water may logically be regarded as more than usually liable to the disturbing agent mentioned. It may, therefore, be taken for granted—though in science the less we have to do with assumptions the better—that under the ocean the volcano discharges its *débris* quite as much and quite as frequently as on the land.

Many facts support this view. Ships navigating the Pacific and other oceans often pass through large patches covered with pumice-stone and other volcanic substances capable of floating, and vast numbers of dead fishes. Occasionally the ocean is found to be boiling as from some disturbance beneath; and boats passing along the shore of Hawaii have more than once been struck by pieces of lava forcibly ejected from the bottom of the sea.

Volcanic Islands.—However, proof still better is afforded us of the work going on under the waters. Many islands, like St. Paul, Ascension, Reunion, Amsterdam (Fig. 84), and Barren Island, are mere heaps of cinders and lava, and doubtless originated by the materials of which they are composed being ejected from the bottom of the ocean. Reunion evidently owes its existence to the mountains of which the Piton des Neiges and Le Volcan are the chief points rising out of the sea. There are two volcanic vents still on the island, and eruptions occur at intervals, though none of them are of any great consequence.† Stromboli and Santorin we know to be children of the sea, and there are good reasons for believing that both Etna and Vesuvius originated in

* On the shores of Feather Lake, Plumas County, California—a region the centre of which is Lassen's Peak, thickly studded with great volcanic piles, and buried thousands of feet deep in ancient lavas—there was an eruption, probably in 1852. From the vent—now covered by a cinder cone—there flowed a very thick sheet of basaltic lava, which nearly filled up the basin. There have also been vague reports of eruption of the North-Western at a still later date, though, with the exception of Mount Baker, which the writer has more than once seen in activity, there are none well authenticated.—Dutton, in *Science*, Vol. VI., p. 46, and Davidson, *Ibid.*, p. 262.

† Vélain: "Les Volcans" (1884), and other works; Bory de Saint-Vincent: "Voyages, etc." (1804); Drasche: in *Bericht der K. K. Geol. Reichsanstadt*, 1875-76.

submarine volcanic vents, and grew to their present dimensions by the gradual accumulation of the materials thrown out around their base, and also by the elevation of the land on which they stood. Finally, there are plenty of instances in which what has been assumed by inference to have happened has actually been seen in operation.

Some three years ago a German trading vessel arrived in Callao with strange tidings. Sailing south from Guatemala to Peru, the master had sighted land where, according to the chart, no land should be, and where in a sea so well surveyed as the Pacific, within hail of the South American shores, it is unlikely that any considerable rock or skerry should exist without being known to the mariners of England or of the United States.* This, however, the seafaring men declared was not the case. About 189 miles west of Punta Ahrija, in northern Peru, they affirmed that they saw with their eyes a new island, about a mile long by a mile wide, and it is almost needless to say uninhabited by human beings. There was quite a rush of ships to the position indicated, a new island being—apart from the glory to be got by annexing, naming, and "taking possession of" it—an awkward thing to run against of a dark night. However, there was no quarrelling, for when the locality was reached no land was to be found. Either the mariners had been "spinning a yarn," or, more probably, the spot which they described was the summit of some submarine volcano, which had disappeared as rapidly as it had emerged from

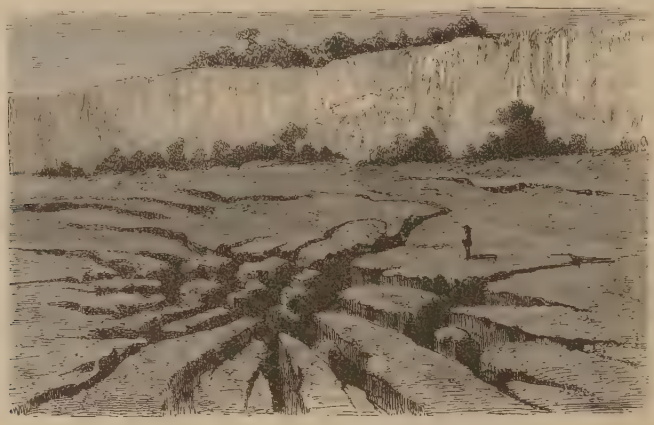


Fig. 85.—FISSURES NEAR LOCARNO, SWITZERLAND.

* There are, however, new islands still to be discovered in the Pacific, some of which may have arisen within the lifetime of the present generation. For instance, in addition to two large ones described very recently, a third was discovered in 1886 by Captain Allison, of the *Fee-Lung*, whilst on a voyage from Sydney to Shanghai. The new island is situated less than 100 miles from the northern coast of New Guinea, between the island of Durour and the Exchequer Archipelago. It has been named after its discoverer, and is officially described as about one and a half miles long, rising from 100 to 150 feet above the sea, and covered with dense timber over its entire surface. Several stretches of fertile and inhabited land, some of them much larger than Allison Island, have been found within a few years at a distance of 200 or 300 miles from the New Guinea coast, and similar discoveries are made once in a while in various parts of the Pacific. Although the maps of the Pacific Ocean are studded with islands which appear to be lying close together, vessels may sail among these islands for weeks together without once coming in sight of land. So vast is the waste of waters that not long ago a crew which had been shipwrecked in the great island region of the Pacific rowed north for forty days before they reached Hawaii, the nearest land. Now and then a trader finds some new or little-known island, and opens barter with its inhabitants. When the Woodlark group were explored some time ago it was found that an Australian firm had several years before been quietly trading there, all unknown to their rivals in the commerce of Oceania.

the waves. In any case, the island must have been a volcanic one, the offspring of some submarine eruption so common off that earthquake-riven coast. Otherwise it is impossible to believe that it could have escaped the notice of navigators. It is also comforting that the sea which vomited it forth swallowed it up, and thus saved all further diplomatic difficulties over its proprietorship. For no one could have any yards. Then naval officers and Foreign Ministers began to take an absorbing interest in it. The names of Nerita, Sciacca, Ferdinanda, Julia, Hotham, Graham, and Corrao, were successively given to it by the fiery mariners who cruised around it, ready to land and hoist their country's ensign the moment the lava and scoriæ cooled, and the lake in the crater ceased to boil. Meantime, however, the sea saved all trouble. The eruption ceased, and,

Fig. 86.—BASALTIC PLATEAUX OF THE COIRON, IN AUVERGNE, FRANCE. (*After Scrope.*)

desire to see the newly-discovered South American pile of ashes play the part of Graham's Island.

This insignificant slag-heap, over which so much ink was spilt, and gunpowder might have been burnt, arose in 1831, some thirty miles off the south-western shores of Sicily. It first appeared above the surface of the Mediterranean on the 18th July of that year, in the shape of a crater twelve feet high, emitting lava and volumes of vapour. But by the 4th of August it had risen 200 feet above the sea level—800 feet higher than the sea bottom—and attained a circuit of 2,300 little by little, the waves asserted their right, until before the winter arrived a shoal of cinders and sand alone marked the position of Graham's Island, which had thus shamefully cheated so many valiant men of the chance of doing something for the credit of their respective countries.

But it is not the only islet which has arisen out of the sea. Of course, the majority of the non-coral isles of the Pacific are volcanic, though history has preserved no record of the time when they first appeared. Local historians have endless tales to tell of other submarine eruptions in the Mediterranean and

elsewhere; and as late as the year 1811 Captain Tillard, of His Britannic Majesty's ship *Sabrina*, was so fortunate as to be able to observe the birth of the isle to which he gave the name of his frigate. From the nearest cliff of St. Michael's, in the Azores, the volcanic bombs and *débris* were seen to break through the surface of the sea with a noise resembling a mixed discharge of cannon and musketry, until it had attained the height of 300 feet and a circumference of half a mile. A proud man was Captain Tillard as he told the Navy Board of his great discovery, though there is a tradition in Whitehall to the effect that when, a few weeks later, he returned to survey his annexation, the English language was found insufficient to express his anguish at finding that the sea had again claimed its own. Not a trace of Sabrina Isle was visible. It had sunk in the Western Ocean, whether devoured by the insatiable breakers or by the subsidence of the general mass there is no material to enable us to decide.

This is not a solitary instance of a volcano throwing up a temporary islet in the same part of the ocean, for in the MS. Journals of the Royal Society we read that Sir H. Sheres informed a meeting of "January 7th, 1690–91," that "his father passing by the Western Islands, went on shore on an island that had been newly thrown up by a volcano, but that in a month or less it dissolved, and sank into the sea, and is now no more to be found." Off the coast of Iceland islands appear and disappear during the many volcanic eruptions to which that remote dependency of Denmark is subject, and at various periods in its history the sea has been covered with pumice and other *débris*, which tell their own tale of what has been going on, without the ejecta being bulky enough to reach the surface in the form of a continuous cone. The sea off Reykjanes—Smoky Cape, as the name means—has been a frequent scene of these submarine eruptions. In 1240, during what the Icelandic historians describe as the eighth outburst, a number of islets were formed, though most of them subsequently disappeared, only to have their places occupied by others born at a later date. In 1422 high rocks of considerable circumference appeared. In 1783, about a month before the eruption of Skaptar Jökull, Nyoe, a volcanic island, from which fire and smoke issued, was built up, and in due time vanished under the waves, all that remains of it now-a-days being a reef from 5 to 35 fathoms below the sea level; and in 1830, after several long-continued eruptions of the usual character, another isle arose, and, at the same time, the skerries known as the Geirfuglaska disappeared, and with them the great auks, or gare-fowls—birds now extinct—which up to that time had bred on them. At all events, though the auks could not well have been drowned, no traces of them were seen after the date mentioned.*

In July, 1884, an island again appeared about ten miles off Reykjanes; but it is already beginning to diminish in size, and may soon disappear.†

Nor does it matter, since there are plenty of other instances of the influence of the submarine forces in raising up and lowering land. The coast of Alaska is a region of intense volcanic action. In 1795, during a period of volcanic activity in the craters of Makushina, on Unalashka, and in others on Umnak Island, a volume of smoke was seen to rise out of the sea about 42 miles to the north of Unalashka, and next year was followed by a heap of cinders, from which some *débris* were ejected, in company with flames, which illumined the country over a radius of ten miles. In four years the island consisted of a large cone, 3,000 feet above the sea level, and two or three miles in circumference. Two years later it was still so hot that when some hunters landed on it they found the soil too warm for walking. It was named Ionna Bogoslova (St. John the Theologian) by the Russians, Agashagok by the Aleuts, and is now known to the whites of that region as Bogosloff. Mr. Dall believes that it has occupied

* Symington Grieve: "The Great Auk" (1885), p. 14.

† The disappearance of "the Monk," a precipitous rock, 100 feet high, off Suderoe, in the Faroes, was due more likely to the action of the sea and the ice sawing through the basalt than to volcanic action, though at the time it vanished (1884) this was hinted at.

the site of some rocks there as long as tradition extends. But, at all events, there were additions to the cone up to the year 1823, when it became so quiescent as to be the favourite haunt of seals and sea-fowls, and, when the weather was favourable, was visited by native egg-hunters from Unalashka. During the summer of 1883 Bogosloff was again seen in eruption, as it was thought. However, on closely examining the neighbourhood, it was found that the old island was undisturbed, but that there had been a fresh eruption, which had resulted in the extension of Bogosloff by the appearance of a cone and crater (Hague Volcano), 357 feet high, connected with the parent island by a low sand-spit, and situated in a spot where, the year before, the lead showed 800 fathoms of water. About the same time Augustin and two other previously quiet islands on the peninsula of Aliaska began simultaneously to emit smoke, dust, and ashes, while a reef running westward and formerly submerged is now elevated to the sea surface. Other islands, of origin exactly similar to Bogosloff and those mentioned, are to be found in this region, notably Koniúgi and Kasatochi, in the Western Aleutians, and Pinnacle Island, near St. Matthew Island.* Indeed, the volcano of Kliutchevsk (p. 123), which rises to the height of over 15,000 feet, is really a volcanic island.

Still more recently—on October 19, 1885—another volcanic island rose in the Pacific, 14 or 15 miles from the island of Honga Tonga; and finally, not to enumerate more examples of submarine disturbances resulting in the births or deaths of islands, it may be added that, in the summer of 1883, an island in the Lake of Nicaragua was destroyed by one of the volcanic outbursts to which that region is so peculiarly liable. The sudden appearance of the islets in the Sunda Strait has already been noted (p. 160), and in a former chapter the later vagaries of Santorin have been sufficiently discussed. We know, from what Pliny tells us—and his statements are confirmed by Justin and Plutarch—that after Therasia was separated, the island of Thera was thrown up, and that in his own time—namely, in the reign of Claudius, A.D. 45—a new rock, called Thea, appeared near Thera. It is not now existent. In 1573 the rock known as the Little Kaimeni was raised above the water; and in 1707 another tiny islet, between Little and Great Kaimeni, appeared, and increased so rapidly that in less than a month it had become half a mile in circumference, and had risen twenty to thirty feet above the sea, constituting a third island, called New (or Nea) Kaimeni, which name it still bears. A year after the principal eruption the sea was still so hot that the pitch melted off vessels navigating in the immediate vicinity, and eruptions of red-hot stones were not uncommon. Its subsequent history we know (p. 132).

It will be readily understood that if the discharges so often mentioned fall into the sea they will mingle with the sand, mud, and gravel, and form new rocks; and that if the ejecta drop into a quiet and tideless depth, they may arrange themselves in beds, into which animals will burrow, so that material originally derived from the igneous rocks will become stratified, just as if it had been worn down by a river and swept into the ocean. But, as the reader will have already learned, this constant re-arrangement of matter is a law holding true of all Nature, and a rock is classed as stratified or unstratified, not owing to the material of which it is composed, but owing to the method in which that material was assorted in the crust of the earth.

The Unstable Land.

We have seen that the volcano tosses the crust of the earth into the air, grinds it in fragments, burns it into ashes, or fuses it into slag, and while one day it causes old landmarks to disappear, on another it brings into being hills and islands hitherto in the womb of the world. When the earthquake, that

* Dall, in *Science*, Vol. III., No. 51, pp. 89–93; *Ibid.*, Vol. IV., No. 92, pp. 432–434; Davidson, in *Ibid.*, Vol. III., No. 54, pp. 186–187, and Vol. IV., No. 97, p. 538; Petroff: "Report on Alaska, pp. 18, 21, 23, 87, 91, 93, 94–96, in *Tenth Census of the United States*, Vol. VIII.

elder sister of the volcano, comes to be considered, it will be seen that it also raises up and depresses the crust of the globe, dislocates its rocks, and forms huge gashes on its fair surface. These results of the subterranean forces of the world are more or less familiar to every one, even when their cause is not understood, since nearly every month we hear of earthquake shocks or of volcanic outbursts in some part of the world. But the newspapers record only such catastrophes as that of Krakatau or of Santorin, of Ischia or New Zealand, of Greece, Spain, Peru, Charleston, or the Riviera, and we are therefore apt to imagine that earth-shaking is exceptional. In reality it is always at work. There is rarely an hour in almost any part of the globe during which some slight shock of earthquake is not felt, even when the tremor can be indicated only by an instrument devised for recording such gentle movements. But even in regions little, if at all, troubled by volcanic disturbances, the earth is often in a state of oscillation, since the result of observations, extending over many years, has been to show that the coast is gradually sinking in one section, while at a little distance it is equally slowly rising. What is more, it is known that places now subsiding must at some former period have been rising. Now, this is not due, as the older writers imagined, to the retreat or advance of the sea. The sea, though going and coming in ebb and flow, always keeps the same average level. It cannot diminish its level locally. It is the land which is oscillating, though so insensibly that it is only after long observation that the fact can be ascertained; though, of course, considering the vast number of years with which the geologist deals, an inch in a century might mean the submergence of a province, or the conversion of a shallow sea into a lofty plateau, within a space of time which would form only a small portion of a geological period.

We thus see how erroneous are popular impressions regarding the forces of Nature. The volcano and the earthquake, powerful as they are, have probably not accomplished a tithe of the work which the slow "secular rising" and sinking have done; and while we talk of the "stable land" and the "unstable sea," it is in reality the sea which is firm, and what Shakespeare called "the harmless earth" which is fickle. "Terra firma" is hard to find.

A glance at the map of the region of secular rising and sinking will show from what regions the facts commented on have been derived, though doubtless, as time progresses, further data, admitting of somewhat broader, and, perhaps, sounder, generalisations than any which have as yet been proposed, will be added to the present fragmentary collection. A few remarks on some of the chief localities in which this "secular"—this slow, imperceptible rising and sinking are going on may, however, enable us to explain the proofs relied upon by those who have arrived at the conclusions accepted.

Elevation.—This seems to be going around through the entire Polar basin. North of Wolstenholme Sound—or somewhere in the vicinity of latitude 77°—the raised sea beaches covered with marine shells, which are found along both sides of Smith's Sound and its continuation, have long been cited to show that within recent periods the coast has been slowly rising (Fig. 87). In places, as at Cape Frazer, these beaches are at an elevation of between two and three hundred feet above the sea level, showing, where a section is exposed, well-defined alternate layers, one-half to two inches thick, of stratified mud and sand.* Sometimes these raised sea beaches take the form of stairs or terraces, the easiest explanation of which is that at intervals the rising has come to a halt, and then, after a period of rest, gone on again, each stair marking a

* Nares: "Voyage to the Polar Seas," Vol. I., p. 341, Vol. II., pp. 66, 153, 154. The authorities for the data given in this section are too numerous to quote. Most of them are well known, and, so far as the Polar regions are concerned, may be found in Mr. Howorth's paper in the *Journal of the Royal Geographical Society*, Vol. XLIII., pp. 240–263, though its generalisations are open to doubt. Many of the facts mentioned are derived from the author's observations, or are embodied in his "Physical Structure of Greenland" (Arctic Papers of the Royal Geographical Society, pp. 1–73), to which the reader may be referred for further details.

period of elevation, followed by a period of repose. At more than one place on the west coast of Greenland fresh-water ponds containing animals of marine origin exist, just as various marine crustacea have been found in Wetter and Wener, fresh-water lakes in Sweden. South of the point mentioned, the coast is, as we shall presently see, sinking. But, as I pointed out in 1869—though the Danish Royal Commission seems to have overlooked the fact, since in the official report of their admirable labours they publish the data as a discovery of their own—these raised beaches or terraces also exist on both the eastern and western shores of South Greenland, where the coast is at present unquestionably sinking. The chances are that if observers were stationed in the country north of Wolstenholme Sound for a sufficient length of time to note the circumstances, it would be found that North Greenland and the neighbouring shore of Grinnell and Grant's Lands do not differ from the region farther south, the raised beaches being in reality of a more ancient date.* Labrador is, however, rising, and the same fact seems to hold regarding Newfoundland; so that probably the entire Arctic shores of America are either rising just now, or have risen within comparatively recent periods; for shells still living in the neighbouring sea are found embedded in sand and clay at elevations 800 feet above the sea level.

Spitzbergen is certainly an area of elevation. Whales' skeletons are found high above the sea level, but whales, which at one time spouted in every bay of these islands, and are still killed in the sea south of them, have now deserted their shores, owing, it is affirmed by the walrus hunters, to the rapidly decreasing depth of the sea in their vicinity; and, from traces found along the Arctic shores of Europe and Asia, there is no reason to doubt that the elevating action exempts these borders of the Polar basin. Among other facts which might be mentioned, the existence of islands east of Novaia Zemlia—on two of which, Brown's and Hellwald's, the northern extension of the Gulf Stream has tossed West Indian seeds—on the spot where, less than three centuries ago, the Dutch navigators took soundings on a sand-

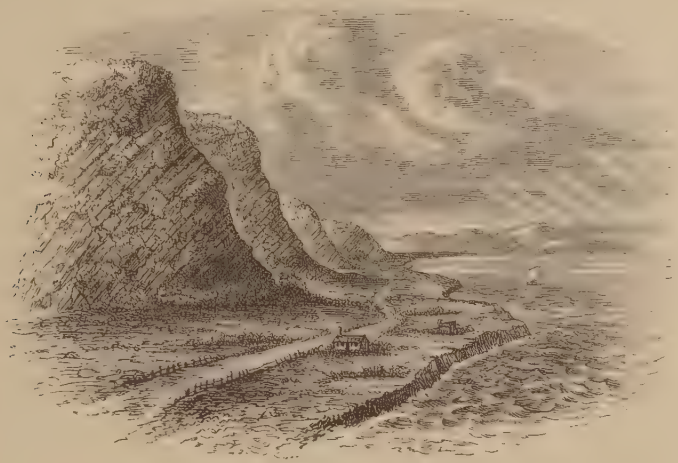


Fig. 87.—RAISED SEA BEACH.

* These facts will be found enumerated in "The Physics of Arctic Ice" (*Quarterly Journal of the Geological Society*, Vol. XXVII., 1871, p. 671), reprinted, with additions, in "Arctic Papers" (1875), p. 50; "Countries of the World," Vol. I., p. 67; "Florula Discoana" (*Transactions of the Botanical Society of Edinburgh*, Vol. IX., 1868, pp. 430–465), and "Arctic Manual" (1875), pp. 256–283.

bank, covered by 18 fathoms of water, is among the most remarkable.

Many portions of America, farther south, could be adduced in support of the same theory. The shores of Vancouver Island and the neighbouring mainland are, for example, bordered by raised sea beaches; and beaver dams, quite perfect, are now seen in places where no water runs, though a beaver never by any mistake builds its dam across a stream which runs dry during the summer season. Scores of similar if not more striking facts could be produced. But some of the best known are to be gathered from the Scandinavian peninsula. In the Gulf of Bothnia there are ancient ports which have been changed into inland towns, "small islands joined to the continent, and old fishing grounds deserted as being too shallow or entirely dried up"; and there are rocks on the shores of the Baltic and in the ocean which were at one time known as sunken reefs dangerous to navigation. The ancients always described Scandinavia as an island, and, from various circumstances, there is some ground for believing that it only became a peninsula between the days of Pliny (A.D. 23—79) and the ninth century. The pilots have the same tale to tell, while the marine shells found high above the level of the sea fortified the observations of these "practical men." This induced the savants to put marks upon the rocks and examine them at intervals. These entirely confirmed the belief that the coast was rising at the rate, in some places, of four or five inches in thirteen years. Reefs are seen where, within the memory of man, no rocks were known to appear above the surface; and long fjords once separating wooded islands have been "deserted by the sea" (to use a popular though mistaken expression) within the recollection of witnesses whom Sir Charles Lyell conversed with some fifty years ago, while reefs once submerged every tide are now little islands supporting a scanty vegetation. The foundations of the Castle of Kalmar, on the Baltic side of the peninsula, are no longer under water; they have risen four feet in as many centuries. The lakes of Husar, Ladu, and Uggel, which two and a half centuries ago—when Karl IX. was King of Sweden—constituted the Gulf of Fiskartop, have grown much shallower and in part become dry land. The marsh of Öregrud, 40 miles north of Upsala, rose $5\frac{1}{2}$ inches in 14 years: and at Gefle, 40 miles to the north-west, there are low-lying pastures where the fathers of people living at the date Lyell wrote remembered boats, and even ships, floating. A series of thirty marks was made, in 1851, on the Baltic coast, from Torneå to the Naze of Norway, in continuation of those the results of which have been described, and in 1884 these were examined by a commission of the Swedish Academy of Sciences. By these observations it was established that the movement of elevation was contained in the north, and that of depression at the southern extremity of the peninsula. About Kalmar and Karlskrona no change of level could be detected as having occurred within recent years. But since 1750 it was proved that the head of the Gulf of Bothnia had risen at the rate of 1·170 metre per century. This rate of elevation declines progressively towards the south. It is not more than 0·30 of a metre at the Naze, and it is zero at Bornholm. The mean elevation of the Swedish coast is thus 1·60 metre per century.*

From these and a host of similar data, no doubt can exist regarding the rise of the Scandinavian peninsula, and inferentially there was a period when the Arctic Ocean communicated with the Baltic. The Japanese islands are also rising, and many districts around the Sea of Aral and the Caspian are in a similar plight, as will be seen by examining our map. It is, therefore, needless occupying more space with proof culled from these quarters. In more southern regions data equally cogent are ready to our hand. Crete has risen 17 feet above its ancient level; the old Greek ports are high and dry; and limestone rocks which the sea never touches are to be found pierced by a species of shell-

* *Proceedings of the Royal Geographical Society*, 1885, p. 543. A metre, it will be remembered, is 3·28, or, to be more minute, 3·28089917 feet.

fish which bores into stone, though, it may be added, so little can any law be formulated regarding these areas of elevation and subsidence that on the eastern side of the island the ruins of several Greek towns may be seen under the water. Marine shells far above the highest tidal mark are found plentifully along the shores of South America, commencing at Tierra del Fuego, and along the west coast for a distance of at least 2,000 miles, and in patches probably as far north as the Isthmus of Panama, these evidences of upheaval being deposited at elevations varying, according to Darwin, from 300 to 1,300 feet over the sea level.

The raised sea beaches which are taken as proofs of the rising of the land, are found not only around the places already noticed, but along the outer coast of Norway, South America—at Coquimbo, for example—and along many parts of the shores of Great Britain. At Brighton, for instance, there is a marked specimen of this in the cliffs east of Kemp Town; while Robert Chambers wrote an elaborate work, mainly descriptive of those to be traced along the Scottish coasts at all heights up to 100 feet above the present sea level.* Again, though belonging to the same class of proofs, the elevation of the coast here is indicated by caves, formed by the constant dash of the waves, being found along the coasts of Scotland, near Campbelltown and Neill, in Cantire, for example, at places far above the reach of the sea, which laves the base of the cliffs in which they are excavated.

In Natal upheaval is still going on, and the eastern coast of Africa is generally believed to be rising; and, just as in North-Western India, the drying up of the rivers and springs has been attributed to the level of the country having changed, so in the country beyond the Orange River, in South Africa, remarkable changes in the water-courses have been traced to an identical cause. Australia, on the north-east, if not on the whole of the east coast, is rising. Mr. Rattray describes water-worn waves well above high-water mark in the sandstone cliffs of Albany Island, and in those of the mainland opposite, while the drainage of the country is altering, and the country several miles inland is covered with recent shells. Until a very late period in the geological history of Tasmania, the site of Hobart Town was covered by the sea; and in New Zealand, though there is an area of depression on the extreme north-western point, the mass of the land is rising.†

Depression.—The sudden elevations and depressions caused by earthquakes will be considered at a later stage in our studies. Yet in plenty of regions, where there are no marked signs of either earthquakes or volcanoes, there is a depression as well as an elevation going on. In various parts of South Greenland, the Eskimo can no longer build their huts in the places where their fathers did before them, owing to the sinking of the coast. The floors of houses on lowish lands are now submerged at every high tide, and the old poles to which the Moravian missionaries moored their boats lay under water at the time Dr. Pingel visited the country some fifty or sixty years ago. One of the streets of the town of Malmö, in Sweden, is flooded by the sea when the wind is high; and at eight feet below the present road the remains of a still earlier one have been found, showing that at the extremity of a region now rising there has been, for several centuries at least, a subsidence going on. A rock at Trelleborg—nine miles from Malmö—which in 1749 Linnæus measured the distance of from the sea, was found, in 1836, to be 100 feet nearer the shore. Submerged forests, such as are found round the shores of Devon, Cornwall, West Somerset, off the north coast of Norfolk from Hunstanton to Brancaster Bay, and among other places along

* "Ancient Sea Margins, or Memorials of Changes in the Relative Level of Sea and Land" (1848). Some of Dr. Chambers's sea margins are, however, rather problematical, though there are plenty to prove the case without taking these doubtful ones into account. In Dr. Geikie's "Scenery and Geology of Scotland" (1865), pp. 193, 318, etc., these features are most lucidly described.

† Howorth: Journal of the Royal Geographical Society, Vol. XLIV., pp. 252–262.

parts of the Lincolnshire coast,* may again be cited in proof of submergence; while the buried valleys and river channels, and the fjords or lochs of the west of Scotland, Norway, Greenland, British Columbia, and other countries enjoying, as most countries do, a damp climate on their westerly side, which were originally the beds of glaciers, are also evidence of the coast having sunk, otherwise water could not occupy what were formerly glens. The southern shores of the Channel are slowly sinking, as is also the coast northward from France to Jutland. Finally, not to multiply instances of the same character, there is no doubt that if we accept the current theory of the way coral reefs are formed—of which doctrine we cannot anticipate the discussion — the submerged lands on which they are built must be regularly sinking.

Alternate Elevation and Depression.—It must, however, have often happened that a region which has been for a long period rising has again sunk, or *vice versâ*. For instance, a hut has been found in Sweden beneath layers of sea-sand and gravel, though the spot on which it exists is now high above tidal mark. It is therefore clear, that as the prehistoric fisherman did not erect his house at the bottom of the sea, it must first have been on dry land, and then, after being sunk with the soil on which it stood, until it got silted over, it was by another change slowly raised into the upper air. But the most noted instance of this alternate elevation and depression is afforded by the Temple of Jupiter Serapis, at Pozzuoli, on the Bay of Baiæ, close to Naples. Its present appearance may be understood by a reference to Fig. 88.

The great marble pillars—three only of which remain—are, up to the height of 12 feet, smooth. But above this level they are, throughout a zone nine feet high, perforated by a burrowing shell-fish (*Lithodomus dactylus*), the valves of which still remain at the bottom of the holes. The temple must, therefore, have been under the sea so as to permit these molluscs to bore in its pillars. But, six feet below the floor of the temple, a second pavement exists, showing that the temple had been sinking even at the time when it was a shrine of Jupiter Serapis, so that it had been necessary to construct a new floor at a higher level. This might have been in the time either of Marcus Aurelius or of Septimius Severus, both of whom helped to restore the building. When the excavations began, the temple area was filled, to the depth of 13 feet, with stratified marine deposits and volcanic *débris*, probably from Solfatara, a neighbouring crater, which beds seem to have protected the lower part of the columns from the shell-fish which burrowed into them above that level. It is therefore certain that at one time Pozzuoli must have been at least 20 feet lower than it is at present. After that date, probably about three and a half centuries ago, the re-elevation began, and was expedited by the great eruption of Monte Nuovo (p. 162). Finally, since last century, the ground on which the temple stands has been gradually sinking, the lower part of the ruin being now under water, though, in order to prevent unhealthy exhalations, the level of the ground has been raised by artificial means. These interesting remains of pagandom, therefore, demonstrate repeated depressions, periods of rest, and elevations, alternating with each other.

Cause of elevation and depression.—From what has been said in the preceding sections, it will be seen that secular rising and sinking of the land, though no doubt due to internal movements affecting the earth's crust, cannot strictly be assigned to the operation of the same causes which produce volcanoes and earthquakes. In the majority of cases, the regions affected are either far away from a volcanic vent or tract, or the connection between the two is not very apparent. Moreover, while an earthquake or a volcano is essentially sudden and violent, this sinking or rising of the land—which seems to have been going on ever since the world began—is so imperceptible

* Jukes-Browne, in *Geological Magazine*, Vol. III., p. 491, Vol. VII., p. 164, etc.

Fig. 88.—RUINS OF THE SERAPEUM, OR TEMPLE OF JUPITER SERAPIS, AT POZZUOLI, NEAR NAPLES.

(After a Photograph).

that it is only from a consideration of the facts mentioned we are able to know that it has occurred at all, and is still in progress. It is also clear that though the circumstances attending the phenomena are much the same throughout wide areas, there are always local peculiarities which compel us to seek for an explanation of the facts in causes to a certain extent of local operation.

The explanations which have been offered are, however, so varied, and frequently so inconsistent with each other, that we are compelled to come to the conclusion that though some of the causes suggested may border on the truth, science has as yet failed to solve a problem the main facts of which have never been doubted. For example, (1) This secular rise and fall of the earth's crust* have been attributed to the swelling of rocks on one hand by heating, and their contraction in another direction by cooling. That this occurs may be taken for granted. In the vicinity of a volcano, or even in a marked volcanic district, it must indeed be of frequent occurrence. Lyell has calculated that a mass of sandstone would raise the rocks above it 10 feet if its temperature was raised by 200° above the normal heat—the elevation being, of course, proportionately greater as the temperature is higher and the beds affected thicker. This augmentation of temperature, however, may be produced by other means than mere local heat derived from a volcano, or the concomitants of one. A heavy pressure caused by superincumbent beds of rock or other circumstances will raise the heat of those lying below them; for (as we have already seen) the isogeotherms (p. 83) in the earth's crust follow pretty evenly the contour of the surface, so that when by the operation of denudation, or the causes which have been continually in operation tending to wear away the rocks, a mass of material is removed from one spot and deposited in another, the isogeotherms of the first-named locality will fall, owing to the diminished temperature of the rocks far beneath the surface, and rise in the other one from the opposite cause. Still, though the facts given are plausible enough, they seem too local to be quite applicable to every district, and, in truth, these causes for a rise or diminution in the temperature of underlying rocks and a consequent elevation and depression of the surface, do not in every case appear to be *apropos* to the places in which the phenomena of secular rise or fall are notoriously present.

(2). Mere mechanical principles have been called in to account for one part of the earth shifting upwards while another is just as slowly shifting downwards. For instance, the accumulation of vast masses of ice around the poles during comparatively recent periods in the earth's history would tend to depress them, while the melting of these loads would allow the crust to gradually relax from the tension under which it lay. Some of the American geologists will go so far as to declare that even smaller weights than those indicated will disturb the equilibrium of the earth—that, for instance, those parts of America which have been long out of water, and therefore not subject to heavy pressure, have risen, while others which have been loaded with heavy masses of superincumbent beds, show subsidences. But this contention cannot be seriously entertained since, as Dr. Geikie points out, to believe that the removal or deposit of a few thousand feet of rock could force the crust of the globe to sink and rise in proportion, takes for granted such a mobility in the earth as could not fail to manifest itself in a far more powerful way under the influence of the attraction of the sun and moon. In brief, terrestrial tides would be the result (p. 84). No doubt, if masses of ice accumulated at either pole, the land in the hemisphere affected would sink, or, in other words, the sea level would be higher, while the contrary would be the case in an opposite direction. Moreover, in consequence of the diminution of centrifugal force, owing to the retardation of the earth's rotation caused by the tidal wave, Dr. Croll considers that the sea level must have a tendency to subside at the equator and

* "Bradysismus," as Arthur Issel ("Movimonti secol. del Suolo," 1885) has somewhat needlessly termed it, from the Greek *bradys*, slow, and *seismos*, an earthquake.

rise at the poles,* though in truth so slow must be any change of level from this cause that the waste of land continually going on would most probably keep pace with it, and thus "diminish the terrestrial area as much as the retreat of the ocean tended to increase it." This explanation does not therefore appear much more satisfactory than the one which we have already dismissed.

(3). The "shifting of the present distribution of density within the nucleus of the planet" would no doubt affect the position of the oceans and the level at which they would stand relatively to the land arising out of them. Indeed, it has already been suggested that the irregular distribution of land and water may be accounted for by this irregular distribution of materials in the interior beyond the limits to which our investigations have as yet been, and most probably always will be, confined. The fact of the Southern hemisphere containing more ocean than continent, and the existence, more particularly, of the Pacific Ocean, has been explained by the presence of some excess of matter in the solid parts of the earth between the Pacific Ocean and the earth's centre, which retains the water in its place. Otherwise the ocean would flow away to the other parts of the earth.†

(4). The idea of Suess and others that the so-called rising and sinking of the land are due, not to any actual shifting of its level, but to changes of the sea level, resulting from oscillations of the oceanic envelope, may be dismissed, since this notion is held by almost no geographer or geologist of any eminence, and, indeed, is made reconcilable with known facts often only by affecting to deny the reality of those which stand in the way of this theory, or ignoring others which there is no getting over.‡

(5). Finally, without explaining the ingenious views of George Darwin regarding the influence which its rotation and the moon's attraction might have on the earth, which are barely compatible with known facts, it may be added that most geologists are nowadays inclined to look to the slow cooling and consequent contraction of the earth for an approximate explanation of not only the wrinkles on its surface but of the phenomena under discussion (p. 36). The influence of this secular cooling on the formation of mountain ranges will be discussed in the next chapter. Meantime, it is enough to say that the earth appears to be a globe which has been slowly cooling by dissipating heat into space, and that the result of this continual though slow loss of its original heat must be to contract its dimensions, since rocks, like most other inorganic bodies, swell by warmth and shrink by cold (p. 174). Mallet, whose name is principally connected with the researches on this question, has come to the conclusion that since the almost incalculably remote period when the earth was a liquid sphere, it has diminished in diameter by at least 189 miles. But though a comparatively thick crust now covers the globe (and whatever hypothesis is accepted as to the structure of the interior, this is certain) the interior must still be parting with heat, through the crust, just—to use an apt simile—as a lava stream which, though liquid in the interior, may be hard enough on the surface to admit of a man's weight (p. 147). But as this contraction of the interior goes on, the outside crust will slowly settle down upon the ever-shrinking liquid interior, be this a molten zone (p. 85) or a more continuous central mass of liquidity. This would, of course, cause a sinking of certain portions. But as the crust which thus falls by its own weight differs considerably in structure and in its power of conducting heat, it necessarily follows that all parts of the interior will not shrink at the same rate, and consequently those parts which sink will not do so simultaneously. However, any mechanic knows that where a more or less stiff arched envelope like the crust of the globe presses inwardly in

* *Philosophical Magazine*, 1868, p. 382; W. Thomson: *Transactions of the Geological Society of Glasgow*, p. 223; A. Geikie: "Text Book," pp. 260, 268–70; and Croll: "Climate and Time" (1875), and "Climate and Cosmology" (1886) *passim*.

† Pratt: "Figure of the Earth," p. 236.

‡ Suess: "Das Antlitz der Erde" (1883), and Trautschold: *Bulletin de la Société Impériale des Naturalistes de Moscou*, 1869 and 1883.

this manner, this inward pressure—as an easily devised experiment would prove—must be attended with proportionately great lateral pressure, which would crush, crumple up into folds, and of course elevate the crust thus affected. How far this has aided in the formation of mountain ranges will be best considered after the origin of volcanic action and the internal structure of volcanoes have been examined. The arguments which have been brought against it may also be more instructively discussed when the theory of mountain elevation is before us. Meantime, it seems that though other influences may have been at work, the doctrine thus briefly stated is more fully in keeping with known laws and ascertained facts than any other which has been placed in rivalry with it. Nature seldom does her work by one agency. Many factors are at her beck. Hence, leaving out of account various others, it is quite possible that rocks when subjected to crushing, and therefore to friction, develop heat, and that the enormous crumpling and crushing of strata, miles in thickness, during the subsidence and lateral pressure resulting from it, would by developing a high degree of temperature so expand the strata that they might, independently of the mere mechanical action described, be by this means raised while it lasted, and lowered when they cooled.

All this is, no doubt, mere speculation. But where inferences must be drawn from data which are beyond our power to check, the theories formulated from such premises must necessarily be vague. But no greater mischief can be done in science than to affect knowledge where it does not exist, since in the eyes of the ignorant the facts which are well established are apt to be doubted and, from the scepticism engendered, to share the fate which, sooner or later, overtakes the children of hypothesis.

But if the causes of this steady rise and fall, this slow emergence of tracts of country out of the sea, and gradual subsidence into it again, cannot be explained with any degree of confidence, there is no disputing the existence of the phenomena. Not only are they going on at present, but they must have been in progress from the earliest period of the world's history. There is probably no spot on the earth's surface which has not been at one time under the water, and certainly none of which the level has not changed more than once. Subsidence and submergence are absolutely necessary for the accumulation of the vast thickness of sedimentary strata, and it is impossible to understand how the great beds of coal separated by strata of limestone, sandstone, and shale, could have been formed without repeated subsidences of the sea-bottom, on which the materials out of which they are composed were deposited. During the Glacial period—a comparatively recent period of the world's history, when much of the Northern hemisphere was covered with huge sheets of glacial ice, as Greenland is at the present day—there are evidences of repeated submergences. The land at that epoch was under water not once but on several occasions; at times it stood at a lower level in relation to the sea than at present, and at other periods it stood at a much higher level than now. "And this holds true not merely of our country, but of every country in the Northern hemisphere where glaciation has yet been found," though Dr. Croll doubts whether these oscillations of sea level resulted from upheavals and subsidences of the land during a very recent period, while regarding it as a necessary consequence from the transference of the great ice-cap from one hemisphere to the other. Here, again, we are in the realms of theory. But when we see the great stretches of strata which have been raised without their horizontality being altered (p. 73), we come back to the confines of fact, which tell us that they were elevated by no violent movement from below, but by some slow, steady upheaval identical with that which has formed the theme of the present section. When the map of secular elevation and depression is studied it will be seen how only a very slight upheaval would unite countries now dissevered, while an equally trifling depression would cause many of the low-lying regions to share the fate which, according to a tradition of the sea, befel that legendary "Land of

Buss" which the old charts figure as existing in the Atlantic, and which, as its site is marked by a shoaler area than the adjoining sea, may probably have been the origin of the Atlantis, over which so much poetry and so much controversy have been spent.* In this spot in the Atlantic the ancient geographers placed the Friesland of Zeno, the Venetian mariner of the fourteenth century, though later commentators have given this mysterious region a much more northern home. Nor is it going out of our way to recall Dr. Wallich's remark, that the Icelandic islands raised out of the sea (p. 166) and again submerged were on a line which, if extended, would very nearly intersect the position assigned to the "Sunken Land of Buss." Rockall—that most westerly bit of Britain "amid the melancholy main"—and, it is not impossible, the Faroes and the other northern isles, may be the remnants of some long vanished land, or stepping-stones by which the flora of Europe travelled to Greenland. Physical geographers, however, in former days were a little too liberal in their application of the possibilities of "bradysismus." When they found a difficulty in accounting for any peculiarity in the distribution of plants and animals they immediately called in the aid of a vanished land bridge—a "Lemuria" in the south, or an "Atlantis" in the north—though their successors, by affirming with dogmatism scarcely less reprehensible and on grounds not much safer, the "impossibility" of such hypothetical lands ever having existed, have shown a proneness to drift to the opposite extreme. Mr. Wallace has, no doubt, given good reasons for discarding the vanished continent extending from Madagascar to Ceylon and the Malay Islands, which was evoked out of the inner consciousness of certain ornithologists to solve the difficulties attending the distribution and affinities of some groups of birds. But between Madagascar and India there are extensive shoals and coral reefs which are always held to indicate subsidence. Hence, we may fairly postulate the former existence in this region of several large islands, some of them not much inferior to Madagascar itself. Moreover, as these reefs are all separated from each other by very deep seas—much deeper than that which divides Madagascar from Africa—we have no reason to imagine their former union.† Even the once discarded Atlantis has begun to revive. But this leads us to consider the cause of volcanic action.

Fig. 89.—EJECTA FROM CRATER OF VESUVIUS.

* In addition to the writers already noted, the following may be usefully consulted:—Hahn: "Untersuchungen über das Auffteigen und Sinken der Küsten" (1879); Penck in *Jahresbericht der Geographischen Gesellschaft zu München*, 1881; Fischer: "Untersuchungen über die Gestalt der Erde" (1868); Fisher: "Physics of the Earth's Crust" (1883); Wallich: "North Atlantic Sea Bed" (1862); etc.

† Wallace: "Geographical Distribution of Animals" (1876), Vol. I., pp. 272–292; and "Island Life" (1880), pp. 392–398; Hartlaub: *The Ibis*, 1877, p. 334.

CHAPTER IX.

Volcanic Action: Volcanic Mountains: Mountains of Elevation.

Cause of Volcanic Action—Difficulties of the Problem—The Reservoirs of Lava—The Origin of the Heat which Melts the Rock or keeps it melted if the Lava is not derived from the Molten Interior of the Globe—Mallet's Doctrine of Contraction and Crushing—A Theory of the Origin of the Lava Reservoirs, and of the Force which empties them—The Gases in the Lava—Some generally-received Dogmas, and Doubts as to their Soundness—Structure of Cones—Elevation Craters—New Zealand Volcanoes—Mountains of Elevation—Discussion of their Origin.

When we come to consider what are the causes of volcanic action, we are face to face with the same difficulties presented by any attempt to explain the kindred—if not identical—secular rise and fall. We are in the presence of forces the results of which are manifest, but the actuality of which is hidden from us far in the depth of the earth. We must, therefore, draw what inferences we can from premises only part of which are open to us, and these perhaps by no means the most important. In the preceding chapters many of the phenomena attending volcanic eruptions were so patent that their explanation required no great acuteness on the part of the observer. But in every case where the problem was so easily solved the phenomena were external. However, when we come to examine the forces which cause an eruption of volcanic matter we are at once compelled to account for—firstly, the materials discharged, and, secondly, the force which sends them to the surface.

The ejecta of a volcano, as we have seen, are water, steam, gases, ashes, slag, and lava. The water is, in the majority of cases, a mere accidental discharge, one which has been ejected from the crater simply because it happened to accumulate there during a period of quiescence, or is the contents of some superficial reservoir which has been tapped during a volcanic outburst. The gases may also, in some instances at least, have been derived from terrestrial cavities not directly connected with the seat of disturbance, though in other instances they seem to be derived either from the decomposition of water, or directly out of the molten lava with which they have been mixed far in the interior of the globe. But all the other materials are dependent on heat. The lava is melted trap—if the term can properly be applied to a material which probably has never been solid—or, at all events, when cooled, solidifies into the igneous rocks which we have learned to know under that family name (p. 92). The lavas, therefore, as they harden when exposed to cold, must have been under the influence of extreme heat in the localities whence they are ejected. The ashes, etc., are also the products of a high temperature, being earth, stones, and other terrestrial materials, which, instead of melting, have burnt into dust or been broken into fragments, or which, having been in a semi-glutinous condition, have hardened soon after they reached the upper world, so that the problem of their origin is identical with that of the origin of lava. We have seen that these liquid materials are of different kinds, and that in the course of their ejection from a volcano they are very regular in their sequence—that is, first one kind comes, and then another, though it seldom happens that all the different sorts are vomited out of the same crater (Fig. 89). One or two may be present, or only one. But in every case where it is possible to follow the sequence, it is affirmed that they always follow a regular order, in which propylites and andesites (varieties of the diorite group) come first, and basalt last. It is, therefore, evident that the reservoirs from which these various lavas are derived must, in some way,

be occupied by molten materials divided into superincumbent layers of different specific gravity, just as in a basin we might have oil on the top, water below, tar in a third layer, and treacle or some heavier substance at the bottom. All four would be liquid. The mass of which they were the components would conform itself to the shape of any cavity; but if, by the application of any force, the cavity were emptied after the manner of the hypothetical lava reservoir under consideration, the contents would be ejected in the air, provided they were in layers of sufficient depth, in the order which they occupied. Yet, though the lavas may be different from each other in minor characteristics, they have so many leading characteristics in common that the conclusion is forced upon us that they all come from a common source, and are due to conditions essentially the same. What is more, the order of superposition mentioned, and the other features described, hold true not only of one country, or of one hemisphere, but of every part of the world.

Here, then, are certain facts from which we are free to infer what we please. If we were at liberty to accept the old theory of a liquid interior covered by a comparatively thin crust, or even a liquid zone intermediate between the hard nucleus and the external rind of the globe (p. 84), our difficulties would be less. For the source of the internal lava would be provided at once, and, as we shall presently see, the means whereby it is ejected less puzzling to find. But the molten centre covered with the thin but ever-thickening shell is a doctrine not so universally in favour as it once was, while the newer hypothesis of the external crust reposing on a molten zone with different "magmas," and itself external to a hardened kernel, is a view still on its good behaviour. It is a "working hypothesis," the sole recommendation of which is that it helps us out of one set of difficulties at the cost of plunging us into a morass of others. Moreover, it is evident that though the cavities—of whatever description—in which this lava is contained prior to its ejection are very extensive, they are not co-extensive with the globe. In many parts of the world—in the "lava beds" of Oregon and Idaho, for example (p. 163)—the molten matter seemed to have been spewed out of the earth simultaneously over several thousand square miles. In Hawaii, outbursts of lava often occur at distances of many miles from the place where it first appears, the rivers, to use the local expression, having "run underground" (p. 151).

But in Hawaii, also, we see—as in Mauna Loa and Kilauea—ejections from two craters comparatively near each other, and yet at different times. What is more, though the first-named crater is at a higher level than the latter, it will often happen that while the one is playing the other is idle, or that both craters will be full of lava at the same time—an impossibility if the reservoir from which both drew their supplies was the same. Moreover, two craters, close together, will often yield, though in eruption simultaneously, different kinds of lava, and it is known that the same volcano does not always discharge the same liquid ejecta, one eruption being mainly of basic, while its successor will spout silicic, these two kinds forming the two great divisions of lavas, corresponding, it is thought by some, to the two great magmas in the hypothetical liquid zone of the globe (p. 85). Finally, from observations made on different eruptions, it has been asserted by sound physicists that the source whence the lavas and other materials come cannot be situated at any great depth in the earth (Fig. 90).

If we accept either the hypothesis of a central liquid mass or a liquid zone, it is not difficult to imagine that as the liquid matter is cooling so it must contract, and consequently the superincumbent crust contract with it, and thus squeeze out in the form of a volcanic discharge the lava and other ejecta of a crater. This doctrine has been ingeniously advocated by Mr. Robert Mallet, who has devoted a lifetime to a study of subterranean disturbances. He considers that this crushing must constantly be going on, and that as volcanoes are usually found in lines along the crest of mountain ranges, these ranges form

the line of the weakest point of the earth's crust, which was broken and elevated by the contraction and consequent crumpling which ensued. This theory, it will be seen, is a purely mechanical one. But Mr. Mallet, by invoking the laws of physics, endeavours to show that in this enormous crushing consequent on the earth's crust accommodating itself to the contraction of the mould upon which it reposes, heat enough will be evolved to melt the rocks, and thus provide the lava squeezed to the surface.

Fig. 90.—IDEAL SECTION OF VOLCANO IN ACTION.

No doubt, if we accept this doctrine, it is not difficult to prove, from the results of experiments, that in the manner described the initial heat might be provided. But it is evidently invoked to avoid the difficulty of providing the ejected matter in any other way, since, on this hypothesis, the central molten nucleus cannot produce the lava; for, as it cools, the nucleus must harden, and the solid crust, as it sinks down to accommodate itself to the ever-contracting mould on which it floats, would not find anything molten enough to force to the surface.

Another predicament which faces us is this. If cooling and contraction, followed by crushing and squeezing, were the sole agents in causing volcanic discharges, we could scarcely conceive them to be so intermittent as they notoriously are. Nor need the minor, though sufficiently awkward, difficulty of explaining how, if crushing originates the heat which melts the rocks, all the lavas ejected all over the world—though on this hypothesis derived from all kinds of rocks—are so extremely alike, be suggested, since it must at once present itself to any one who judges Mr. Mallet's ingenious ideas from the standpoint of ascertained facts. If once we could get over these primary obstacles to its acceptance the secondary ones might be kept in abeyance.

We must, therefore, turn to the other theories which have been offered in explanation of volcanic disturbances. A lava reservoir is essential. This, according to the view we are about to state, may be found in the presence of detached reservoirs in the crust of the earth, which are constantly filling and emptying. But how these cavities come to be in the centre

of the solid rind has not been explained. It is, however, more than possible that the contraction of the central molten interior of the earth is not uniform. The crust is at places thicker than at other spots, and the superincumbent beds may be worse or better conductors of heat; or other circumstances, of the nature of which we are still ignorant, may have interfered with the regular secular cooling of the interior mass, so that large cavities communicating with the central nucleus are still unhardened, and after being emptied by a volcanic discharge, fill again by the welling up of the molten matter deeper down. To cause the initial discharge, it is quite possible to accept Mr. Mallet's agency of crumpling up of rocks, and it would be wasting the utilisation of possibilities to reject his contention that heat is generated during this operation. But there is nothing incompatible in thinking that after a volcano has been established other causes may operate in determining the eruptions. Let us suppose the existence of such a cavity as that described above. Into it wells lava from the source indicated, and over the lava intensely-heated steam must form from the infiltration of water in that form out of the surrounding rocks, until a time comes when the cavity can contain no more and an explosion ensues, which blows off the cover of the cauldron, and forms the "pine tree-" like cloud of steam which is almost invariably the first product of a volcanic eruption. Then into the vacant space the lava wells up, and pours skyward through the funnel formed or cleared by the discharge of steam. After a time the cavity is exhausted and the equilibrium restored, until the feeder filling it more slowly than it was emptied by the volcanic violence, a second eruption is the consequence. It may sometimes happen that by some movement in the interior of the earth, by some such derangement of the crust as might be caused by the contracting and crumbling which unquestionably exist, the connection between the reservoir and its fountain-head is cut off only to be re-established after a long period of quiescence such as is so frequently noted in volcanoes, or possibly to be destroyed for ever when the volcano becomes what we know by the qualified term, "extinct."

All volcanoes, we have seen, discharge certain gases, and as the lava after its ejection continues to emit them, there is just reason to infer that at least some of these have been originally mixed with the molten rock. Some writers, indeed — among others, Tschermak * and Reyer †—will not hesitate to affirm that the activity of volcanoes is in no small degree due to the continual explosion and effervescence of these contained gases, just as water boils over a vessel by the expansion of the bubbles of steam in the water. This may possibly be true, for as Nature never does her work by one agent alone when she has two at her disposal, the earth in labour with a volcanic discharge calls unto its aid many forces. However, it seems to us that the theory here formulated, if not without its drawbacks, is more consonant with known laws and facts than any other. It enables us to correlate the physical as well as the physico-chemical hypotheses, and even to explain the curious discrepancies in the temperature of the earth at different places and at different depths (p. 83). Nor perhaps is it the less acceptable for the reason that while it does not reject altogether the old and still very generally received idea of a molten interior, it modifies this doctrine so far as to reconcile it with the views of all save the most extreme of the astronomers, who, without being geologists, insist on regarding the earth as "rigid as a ball of steel or crystal," which we know that it is not, ‡ while it enables us to dispense with Mr. Fisher's intermediate zone of molten material, which is rather harder

* "Ueber den Vulcanismus als kosmische Erscheinung" (*Sitzungsberichten der K. Akademie der Wissenschaften in Wien*, 1877), p. 151.

† Beitrag zur physik der Eruptionen" (1877).

‡ For some pertinent remarks on this subject, and on the unadvisability generally of shoemakers, no matter how skilful, going much beyond their lasts, the reader is referred to a letter of Professor Newberry in *Science*, Jan. 28th, 1887. This distinguished geologist advocates the old theory of the centre of the globe being liquid. At the same time the question of volcanic action is one so essentially dependent on thermal laws that the physicist is quite as much concerned in its discussion as the geologist.

to hold with than the old doctrine which it is intended to displace.

Having said this much, it is, perhaps, unnecessary to explain any of the many other theories which have been put forward to account for volcanic action, since we believe no one of any weight thinks of invoking them now-a-days. Nor will one of them keep together when subjected to criticism. For instance, Sir Humphry Davy suggested that if immense quantities of the metallic bases of the earth and alkalies were present in the interior of the earth, their oxidisation from contact with air and water would produce all the phenomena described. This theory, which is absurd in spite of the force of its authority—since there is absolutely nothing to support it—was abandoned by Davy long before his death, though since then it has been taken up and advocated by Daubney and others.

Like Bischof, who assumed that steam —derived from water acting on the assumed molten interior—was the agent which initiated volcanic action, these theorists placed great stress on the supposed fact that the large majority of volcanoes are situated near the sea coast. Darwin, on the other hand, contended that volcanoes are almost solely found in those areas of the earth where subterranean motive force is elevating, or has lately elevated, the crust of the globe, and are absent in those where the crust has subsided, or is still subsiding. As for volcanoes being chiefly in the vicinity of the ocean, this very generally accepted generalisation is open to question. At all events, it has been overstrained. For nearness, all depends upon what is meant by that term. If ten miles is regarded as near, then very few volcanoes are within that distance of the ocean. If, on the other hand, we say two hundred and fifty, the statement holds good, but is shorn of a large part of its meaning. The great volcanoes of South America are distant, on an average, about one hundred and twenty miles from the Pacific; while the volcanoes active in America during the middle and late Tertiary time—and here we may add that there is no reason for believing that the old volcanic discharges were more violent than the modern ones, or in any way different in action—do not bear out the dogma; for many of them were 500 to 1,000 miles away from any body of water, and those of Central France and Germany were almost as far from the ocean as the configuration of Europe would permit. Again, taking New Zealand, though Egmont and White Island are near or in the sea, Tuapu and Tongariro are in the centre of the North Island. Captain Dutton, who has made these apt comments on the view under consideration, is scarcely less sceptical regarding the equally widely-received and, as we have shown, more substantial doctrine of volcanoes taking a linear arrangement. It has a large amount of truth in it, but "it has been enormously overloaded and overworked by writers of general treatises." The occurrence of half-a-dozen to a dozen small cones upon a single line of fracture, fifteen to fifty miles in length, is frequent in districts where the volcanic action has been very diffuse. In South America the linear arrangement is very marked in the Andean cones, though there is no evidence to bear out the assertion that any six, or even any three, of them have been built up over the same line of fracture, as would be the case supposing Mallet's theory to be universally well founded; and if the same rule were to apply to the other volcanic belts it might possibly be found that the generalisation was not less faulty.*

* Dutton, in *Science*, Vol. VI., No. 137, pp. 255, 256. His remarks on the volcanic problem ("Hawaiian Volcanoes," pp. 183–198) may also be profitably studied, though he occupies himself with the depressing task of bringing destructive criticism to bear against every hypothesis of volcanic action as yet advanced, without replacing them by one better fitted to bear examination. In fact, he is driven in despair to accept, as the only possibility in sight out of the perplexity, the hypothesis that, as the result of causes hitherto undiscovered, heat is generated in some localities within the earth, and that such local increments of heat produce all the phenomena of Vulcanism. Apart from the circumstance that the necessity for finding lava cavities and heat is not the most urgent factor in the solution of the problem, this is cutting the Gordian knot instead of untying it. It is, he admits, an arbitrary postulate—a simple appeal to a mystery. "It is a chain with the primary links missing—an arch

Structure of Volcanoes.

A volcano is, therefore—to condense the lessons we have learned in the preceding chapters—"a more or less perfectly conical hill or mountain formed by the successive accumulation of ejected matter in a state of incandescence or high heat, and having one or more channels of communication with the interior of the earth, by which the ejections are effected." This definition, which is Lyell's, is sufficiently comprehensive for all practical purposes, though, as we have seen, there may be volcanic eruption in which the discharge consists of lava only, without the existence of a cone or even of a crater (p. 163). These cases are, however, exceptional, and for our purposes may be regarded as non-existent. A typical volcano would, therefore, if cut down the middle, show a funnel going up the centre of the cone and ending in a crater at one end and in the lava reservoir at the other (Figs. 55, 90, 91, 92). When the volcano becomes quiescent, or decreases in power, the chimney is apt to get filled up with ashes and other *débris*, which fall out of it from the sides, and if the volcano has formed under the sea—as many of the old volcanoes did—then the structure of the mountain is complicated in various ways, owing to the water having taken charge of the lighter materials when they were ejected, and rearranged them at its own will. Even the weightier lavas, when suddenly cooled under the pressure of a heavy mass of water, must differ widely from the same material, permitted to roll down the mountain side and consolidate slowly, while bubbles of gas are being given off freely. At one time it was believed that firm lava, like what is found on the sides of so many volcanoes, could not possibly lie there, the slope being too steep for it, and that therefore when such an outpour was found in such a situation it must have originally fallen and cooled on flattish land, the ground being subsequently raised bodily into the cone-like position in which we now find it. Consequently Von Buch, who was the author of this hypothesis, called such cones "elevation craters."

Such a doctrine is now known to be entirely erroneous, for it is found that not only will scoriaceous or vesicular lava consolidate on steep slopes, but from observations made in Hawaii and on Etna it has been found that continuous beds of compact stone have formed on slopes of 15, 36, 38, and even of 40 degrees, to a thickness of many feet, and that the different layers of the different outpourings overlie and underlie the beds of scoriæ which formed part of the same currents.* Apart, therefore, from numerous proofs derived from the contour of the country, there is nothing in the nature of lava to support the soundness of the once popular but now exploded doctrine of cones having been elevated, or that they are not formed, as we have more than once indicated, by the materials thrown out by the crater, as, on a smaller scale and, of course, in a primarily different manner, the cone of a mole-hill is composed of the earth thrown to the surface by the living force beneath. In other words, volcanoes are what the geographer knows as "Mountains of Accumulation," whether they are on a level plain or on the crest of mountains, crushed and squeezed into lofty ridges before the volcano came into existence. Some of the salient facts regarding volcanic discharges are well shown in Mount Wellington (Figs. 93, 94), a long extinct volcano in the Auckland Isthmus, in New Zealand, which shows an instructive series of craters and cones. The oldest bed is a layer of tufa (C), which is cut through by a road (E-F), and in the northern section of the road the layers of this tufa are very perfectly shown; these beds have a slope of from eight to ten degrees. In the crater from which the tufa was discharged stands a cone of slag with two small crater-like hollows. The streams of lava which proceeded from these old points of eruption show here and there in the

without a keystone." It undoubtedly sweeps away the difficulties which encounter all other hypotheses, but it substitutes a perplexity as great as all the others put together. But probably the missing link may yet be found, and the unquarried keystone put in its proper place!

* Lyell: *Philosophical Transactions*, 1858.

shape of stony sheets in the bottom of the tufa crater (G). After what appears to have been approximately a long period of quiescence, a new eruption seems to have poured over the southern edge of the crater. This discharge consisted of the copious and beautiful scoriæ or slags of Mount Wellington (A), which was the result of a considerable stream of lava. These younger cinder beds rise from a circular base at a steep angle of from 30 to 32 degrees. The cone is cut off flat, and encloses the top of a crater, with three openings into it. A small part of the lava has run north into the tufa crater, but the main portion has continued its course in a westerly direction, where it forms widespread fields of lava (D).

the entire structure is a mass of tufa divided into beds, and rising in a gentle slope from the level ground (*a*). The formation of this section of the volcano indicates that at the outset the early discharges were under the sea—the tufa beds having clearly been subjected to the stratifying action of water (p. 167). On these tufa beds reposes the second portion of the volcanic pile—namely, the lava flows (*b*), with an incline as steep as 10°, also formed of superimposed outpours and branching lava streams, alternating with layers of ashes, cinders, and scoriæ. These indicate the second stage of eruption, the one in which the volcanic action was most intense. Lastly comes, as the coping-stone of the cone, a heap of

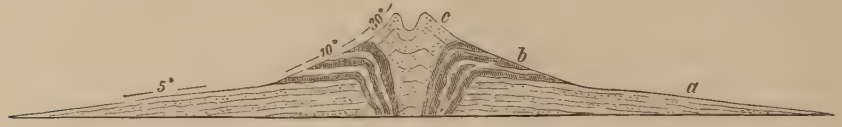


Fig. 91.—DIAGRAMMATIC SECTION OF MOUNT WELLINGTON, NEW ZEALAND.

a, Beds of tufa; *b*, Lava beds; *c*, Ash and scoriæ accumulations, filling up the crater during the last stage of an eruption. The figures indicate the gradient of the slope.

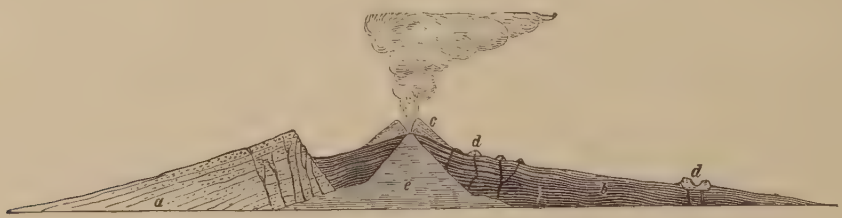


Fig. 92.—DIAGRAMMATIC SECTION OF MOUNT VESUVIUS.

a, The Somma, an old prehistoric tufa hill (p. 129); *b*, The Lava outpour of Vesuvius; *c*, The accumulation of ash immediately around the crater; *d*, Smaller parasitic cinder cones (p. 147); *e*, The interior "Lavaraum," or lava reservoir of the cone.

Every considerable volcanic mass which owes its existence to a long-continued course of eruptions, becomes in this way a more or less complicated collection of these simple outflows and discharges, which we have briefly described as composing the cones of Mount Wellington. If we picture to ourselves the mountain as built up in a perfectly regular manner, then it would consist of three divisions (Fig. 91). The basis and foundation of ashes, cinders, and lapilli, rising steeply at an angle of 30° or more, though somewhat loosely spread (*c*). This completes the third and last period of violence, when the volcano was capable only of discharging ashes.

In addition, we must picture to ourselves the entire cone cut through by dykes of lava corresponding in every respect—except that they do not penetrate ordinary stratified rocks—to those wall-like masses of igneous

rock of older date which have been examined at an early stage in our studies (p. 100). These more or less vertical veins of lava fill up fissures extending from the crater, the funnel of which forms its downward continuation. Into these the molten matter has forced itself, and in some instances they have formed the channels through which secondary eruptions

Fig. 93.—MOUNT WELLINGTON, IN NEW ZEALAND.

A, The most recent Slag layers; C, Tufa beds; g, Tufa crater; D, Lava streams; E-F, Road across mountain.

have taken place, the proofs remaining in the shape of small parasitic cones on the sides of the central one. On Etna, for example, most of the lava streams have poured out of the fissures in the mountain's flanks, the most remarkable feature of this celebrated volcano being the number of parasitic cones which are found within its area. Monte Minardo, near Bronte, the largest of these newer cones, is 750 feet in height. There are eighty others less conspicuous, but von Waltershausen has mapped fully 200, while more recent students of the mountain bring the total up to 700 by including in the list every monticule of ash, and—as Mr. Rodwell suggests—all the "bocche" and "boccarelle" from which lava or fire has ever issued. Monte Rossi, a conelet of reddish-coloured cinders, 450 feet high, and two miles in circumference at the base, was raised during the eruption of 1669; but none of the others of any great importance have arisen during the historical period. Most of them are now covered with vegetation, which shows that the volcanic force has taken other outlets, the violence with which the comparatively loose materials of the mountain were shaken during great eruptions tending, no doubt, to open numerous new fissures in its substance. It is more than probable that the fountain-head of the lava discharges of many of these volcanoes is not very deep-seated. The tendency of the volcanic force to seek new channels is, indeed, so marked that it is rash to say that any volcano is extinct, for some seat of volcanic force, which for ages has remained quiescent, may, when least expected, be suddenly tapped or subjected to the still unknown conditions which precipitate an eruption. It is even possible that in some, if not in all, volcanoes the base of the cone is a hollow, surrounded by a shell of hardened material, which hollow gets filled with lava shortly before an eruption. Most likely, as long as the volcano continues active, part of the material brought forth by the earlier eruptions, and already consolidated in the upper part of the lava reservoir, is again melted. At the same time, the intense heat

Fig. 94.—SECTION THROUGH MOUNT WELLINGTON, FROM NORTH TO SOUTH.

A, The most recent Slag layers; C, Tufa beds; N, North; S, South.

developed by the rising lava will melt part of the interior of the mountain, which has been burst through and broken into fragments, so that in time a vast hollow must form immediately beneath the point where the *débris* are discharged through the funnel, albeit this funnel may be a very short one. In this way the cone may not be so much a conical accumulation of volcanic ejecta, cut through by a narrow shaft-like chimney, as a hollow hill. Looking at it in this way, the outer walls of an active volcano rich in lava represent a mantle of layers of *débris* covering a hollow interior, which, before an eruption, is filled up of lava welling up from below, and after the eruption again becoming empty, the lava still undischarged sinking back into the reservoir from whence it came. This hollow may be called the lavaraum, or lava space (Fig. 92).

The presumed existence of this interior structure explains the frequency of eruptions bursting forth from the fissures on the side of the cone (p. 185). This theory again enables us to understand two peculiarities which are commonly found, though in some respects the two are fundamentally the opposite of each other. In the first place it is frequently noticed that rounded bosses—the "vulkanische kuppen" of the Germans—composed of masses of lava, seem to have poured out on the surface, and there remained in the shape of a dome-like hill. On the other hand, we have seen that in ringed volcanoes, when the top of the cone is blown off it leaves an extensive kettle or caldera, inside of which very often a second cone will form, and if the head of this meets the like fate, a third cone. However, we can imagine one of two things happening to a volcano when the eruption ceases. In the first case the crater of a volcano closes gradually, while the pressure from below is still sufficient to fill the interior hollow with liquid lava, without, however, causing any eruption through the crater or the fissures in the sides. In this case a kernel of stony lava will form inside the "mantle" which covers this cone, this kernel, on account of its slow cooling, having a much more crystalline structure than the older and more rapidly cooled lava of an eruption. Volcanoes of this character are most likely closed for ever. They become extinct, and thus the denuding forces wearing off the mantle of the cone, leave the hard kernel in the shape of an isolated boss, with a "neck" of lava stretching far into the interior of the earth. Such cupola-like remains of ancient volcanoes have been described by Von Seebach as "homogeneous."* And though possibly enough some of these bosses of trachyte or phonolite may have been mere outpourings of lava on the surface—as in Fig. 55, where the surplus is flowing off in a sheet,—in the greater number of instances they are too regular not to have been cast in some such mould as that indicated, and even when a sheet-like prolongation is noticed, this may be merely a lava flow through the side of the cone of loose ashes and *débris*, which has long ago disappeared.

In the second case, when the activity of a volcano has stopped suddenly, either on account of an earthquake interfering with the direction of the subterranean forces, or on account of an eruption through a neighbouring crater, then the lava inside the crater will as suddenly sink out of sight and the cone will remain hollow, with an open or slightly covered crater. After a time, either by one of those immense subsidences by which the shell of huge volcanoes falls in, or by the top being bodily blown off by a sudden blast of steam, heralding a fresh eruption, all that remains of the original cone is the base, with an enormous caldera—the remnants of the pristine hollow (p. 129). Then if a fresh eruption occurs, a second cone will form inside the ringed volcano, as in Vesuvius, with an "atrio," or valley-like space, between them. For this kind of volcano —unlike the other or "homogeneous" one—cannot, as a rule, be extinguished for ever; the activity may begin again after a shorter or longer period of repose, the funnel being nearly choked up with loose *débris*, or even

* *Zeitschrift der Deutsch Geologische Gesellschaft*, Vol. XVIII., p. 643; Von Hochstetter: "Ueber den innern bau der vulkane" (*Neues Jahrbuch*), &c., 1871, p. 469; and the works of Verbeek on Sumatra and Krakatau (p. 162).

open for the continuous discharge of steam and gases.

Mountains of Elevation.

It is thus evident that all volcanic mountains are mountains of accumulation; that is to say, they build up themselves, and, though the creatures of subterranean violence, do not necessarily infer the prior existence of those prodigious upheavals and disturbances of the strata which have given birth to the mountains which form the subject of this section. But even at this stage of our reading of the earth's story it is proper to warn the uninitiated not to jump to the conclusion that all mountains which are not volcanic are due to upheaval and crumpling of the strata, such as we shall presently describe. On the contrary, many of them are really cut out of the solid block of a plateau by rivers and other agents forming glens and valleys around them, and by the harder rocks being left behind, while the softer have succumbed to the action of the elements. These modes of mountain-building will, however, come to be considered more suitably when the various agents which have been employed are studied under the head of "Denudation." Meantime, we are called upon to examine those great folds in the earth's crust which must have been caused by some violence akin to, if not identical with, volcanic action.

Fig. 95.—PROFILE OF THE ALLEGHANY MOUNTAINS, NORTH AMERICA.

m, Miocene beds; *e*, Eocene beds; *k*, Cretaceous formation; *n*, Permian (New Red Sandstone); *c*, Carboniferous formation; *d*, Devonian; *si*, Silurian; *krs*, Crystalline schists.

If the reader will turn to an ideal section such as that shown on p. 75 (Fig. 35)—though in reality there are many actual regions much more crumpled than this one reduced to diagrammatic form—or to those on pp. 187–189 (Figs. 95, 96, 97, 98), he will see that the beds there shown could never have been deposited in those positions. They contain fossils and other unquestionable evidence of their aqueous origin, and, of course, this being the case, of the materials composing them having been deposited in a horizontal position. They must, therefore, have been displaced at a

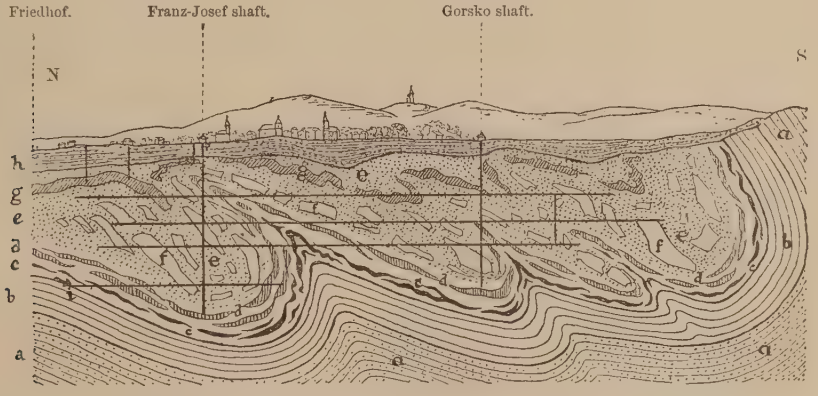


Fig. 96.—SECTION OF THE SALT-BEARING STRATA OF WIELICZKA, GALICIA.

a, Carpathian sandstone; *b*, Sand with gravel, clays, and sandstone; *c*, Marls and salt; *d*, Spiza salt beds; *e*, Salt clays; *f*, Green salt lumps; *g*, Gypsum deposits; *h*, Diluvium; *i*, Place where the water has broken in.

subsequent date. Now, this displacement does not consist simply in the beds being tilted up; they are bent into folds, and in many instances so crumpled that it is almost impossible to follow the minute and endless reduplications of some of the thinner layers of rock.

These facts, whatever may be their explanation, are unquestionable. In trying to account for them we must examine the lay and the position of the chief ranges which owe their elevation to plications of this character. Most ranges we find are composed of rocks which have been subjected to this lateral compression, so that the phenomenon is not of local, but of universal occurrence, and must, therefore, be explained by a cause of equally wide application. We also see that these ranges are of widely different ages, so that they must have been elevated at widely different periods in the world's history; and, what is more, there are good evidences for showing that they have been elevated to their present position by several successive upheavals. It has also been pointed out by Dana and other writers, that mountain ranges are chiefly developed along the borders of continents, and that the highest mountain ranges face the largest and deepest continents. But even admitting this generalisation to be true in the majority of instances—though the exceptions are neither few nor unimportant,—the distribution of sea and land has so considerably altered since the was upheaving, the condition of the other might have been altogether different from what it is at present. But it is more to our purpose to note that mountain ranges enclose "basins or trough-like areas"—concavities between the convexities of the folds. It is also noticed that the crumpling of the rocks increases as we approach the axis of the range, those on the slopes being less disturbed than those which form the ridge; and that in every case the axis of their long folds is parallel to the length of the chain. This shows that the forces acting on the rocks must have been from the sides. Nor, in studying this subject, must we omit to notice that the rocks thus crumpled are, in the central part of the chain, frequently metamorphosed, as if they had been subjected to the combined action of heat and pressure, which, as we have already seen, are important metamorphic agents, heat likewise resulting from the crushing of great rock masses (p. 180). It is also in evidence (p. 46) that there have been repeated upheaval and subsidence of some mountain chains—of the Alps, for example, before the range took its final elevation—facts which we ascertain chiefly by the unconformability of the beds of different ages. This, it is needless to point out, complicates the structure of those oft-disturbed alpine masses. Mountains are, however, sometimes of great age, though it does not always follow that

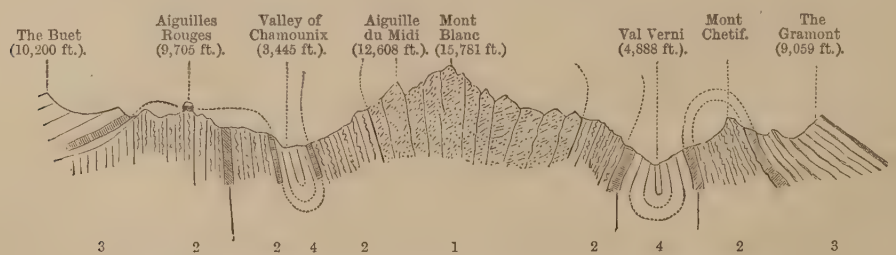

The Buet (10,200 ft.).
Aiguilles Rouges (9,705 ft.).
Valley of Chamounix (3,445 ft.).
Aiguille du Midi (12,608 ft.).
Mont Blanc (15,781 ft.)
Val Verni (4,888 ft.).
Mont Chetif.
The Gramont (9,059 ft.).
3 2 2 4 2 1 2 4 2 3

Fig. 97.—SECTION THROUGH THE CHAIN OF MONT BLANC. *(After Favre.)*

1, Fan-shaped beds with synclinals; 2, Crystalline schists; 3, Triassic strata; 4, Jurassic strata.

formation of such ranges, that it is idle to compare these comparatively ancient mountains with their comparatively modern continental borders, since at the time when the one when the crest is formed ot granite, or other ancient rock, that beds of a later date have not been laid on it, and have subsequently been removed by the action of the elements.

Indeed, in the squeezing process some rock of great antiquity is caught between lateral masses of much less antiquity, and by pressure stands out, as it were, the pinnacle of the mountain (Figs. 35, 98). On the other hand, the Alps are among the youngest of the family of mountains, so that the phrase, as "old as the hills," is to the geologist a very relative term. The newest rocks are old compared with man and his organic surroundings. But the Alps, for instance, are of yesterday when their remoteness is put into comparison with the still more-incalculable antiquity of others which may be found at a few miles' distance from them. In like manner, it is not consonant with geological knowledge to say that "the hills endure for aye." On the contrary, it is perfectly certain that they are wearing away every minute, and that since they were first called into being vast masses of rock have been removed from them by the influence of agents still busy at work—to wit, water in its various forms. In truth,

> "The hills are shadows, and they flow
> From form to form, and nothing stands;
> They melt like mist, the solid lands,
> Like clouds they shape themselves and go."

Meantime, however, we are concerned, not with the agencies which wear down mountains after they are reared, but with the forces to which those included under the head we are now discussing are indebted for their upheaval.

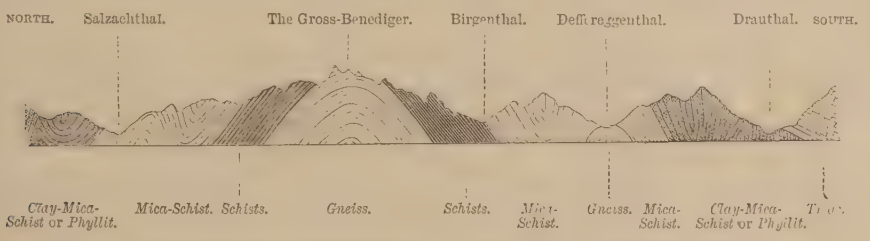


Fig. 98.—PROFILE OF THE CENTRAL CHAIN OF THE EASTERN ALPS.

Causes of upheaval.—Most geologists are agreed that the secular contraction of the molten interior of the globe, and the consequent subsidence of the solid crust of the earth to accommodate itself to the diminished size of the mould on which it rests or floats, is the most probable means whereby this crushing, lateral squeezing and folding of rocks could have been accomplished (pp. 36, 85). This contraction we have already invoked as the cause of secular rise and fall (p. 175), and we have seen that, hypothesis though it is, it has been considered by Mallet as the chief cause of volcanic action (p. 180). To accept this theory it is necessary to hold by the old idea of the molten nucleus, covered by a hardened rind, in which the stratified rocks are superimposed; and perhaps for all practical purposes it is as safe a view to cling to as any other, more especially since, by the observations of Hennessy and Delauney, considerable doubts have been thrown on the soundness of a theory which depends on the supposed influence of the moon in producing tides on a thin crust. If so, we can hardly doubt that such a central nucleus might be cooling, though slowly, for if the fountain-head of internal heat is not constantly being renewed, the prodigious amount of warmth given off by volcanoes alone—leaving out of account the constant loss by radiation—must sensibly decrease its external temperature, and, of course, as cooling causes contraction, its bulk. The rest is a natural sequence. It might at first sight be imagined that a rigid rock is incapable of bending in the manner shown in Figs. 95—98, or in Fig. 99. But it is clear that they must have yielded to strain, since there is nothing more certain than that they were not laid down in this shape, nor crumpled while they were soft, and certain facts tend to show that even the most rigid

bodies may under certain conditions be bent in a manner quite as remarkable as anything seen in the earth's crust. Lateral pressure also produces such folds. The experiment of Sir James Hall, which consisted in subjecting layers of cloth under heavy weights to lateral pressure, is well known. It resulted in the mass showing folds in appearance very much the same as those in rocks believed to have been exposed to similar treatment on a larger scale. Again, even better results were obtained in an experiment of M. Favre's with layers of plastic clay and india-rubber, placed under conditions much the same as Hall's layers of cloth (Fig. 99). This crumpling demands the acceptance of some such hypothesis as that mentioned, for it is clear that if the earth's crust only just serves to envelop the interior in its crumpled form, it must when smoothed out have covered a much larger area. In other words, the earth if "ironed out" would be a great deal larger than it is, with so many of the plaits on its surface, in the shape of mountain ranges. It also follows—though this is not theory, but fact—that in a wrinkled district, with the strata folded in the manner portrayed, the synclines, or troughs (p. 74) would form the valleys and the anticlines, or saddles, the ridges. In a few cases this really happens, though again the influence of the elements so acts upon the plaited beds that, as in Fig. 35, a valley may often be found on the crest of an anticline, and it is quite possible to imagine that by the continuous action of the same process of degradation, a syncline of hard beds would remain in the shape of a hill, while the anticline had left nothing save a hollow behind it.

We have, however, seen enough of the difficulties which face any one when dealing with the possibilities depending on the action of an internal force, the very existence of which is only hypothetical, to be prepared for the doctrine of mountains of elevation being due to secular contraction not receiving universal acceptance. Naturally, the advocates of a solid terrestrial nucleus cannot hold with it; nor is it in accordance with human nature for the physicists who find the solution of so many problems in a liquid zone between the external crust and the supposed solid nucleus to acquiesce in a hypothesis which dispenses with both. Other theorists will admit that though it may be equal to the production of folds like what we find in many strata (p. 74), it is asking more than contraction, and the consequent subsidence followed by crumpling into ridges, can supply. Mr. Fisher, for example, while admitting that the wrinkles on the face of the globe have been produced by lateral pressure, denies that secular cooling is adequate to their production—a contention which he endeavours to support by various ingenious arguments of a very technical character. Captain Dutton will even go farther, and declare that mountain ridges could not possibly be produced by any such hypothetical secular contraction; for the strains set up in the crust by a shrinking nucleus would be such that for any given amount of corrugation with the axis of the folds in one direction, there must be an equal amount with the axis at right angles to that direction. Hence, instead of having lofty mountain ridges, in long

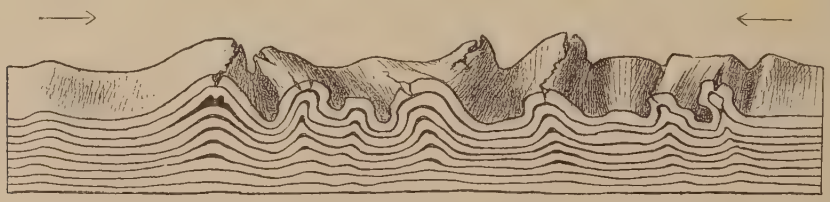


Fig. 99.—SHOWING THE ARTIFICIAL FOLDS PRODUCED IN A SERIES OF LAYERS OF CLAY AND INDIA-RUBBER, ACCORDING TO AN EXPERIMENT OF ALPHONSE FAVRE.

(The arrows show the direction of the contraction.)

narrow belts, with the axis of the folds all approximately parallel, and with no corresponding plication at right angles to them, the earth would be covered with a network of wrinkles, the ridges of which would not equal any but the lowest ranges of mountains. Accordingly, this ruthless iconoclast declares that the great interior of the earth has not as yet undergone any sensible amount of cooling, and therefore, that being the case, it is calculating without one's host to infer such weighty consequences from the hypothesis of a shrinking nucleus, with an outward shell following it downward, and crushing, and crumpling, and localising its collapse at the weakest points in its periphery.* All of which (it seems to us) is doing what the critic stigmatises in his opponents—assuming something, and then arguing on the assumption. The only substitute for the hypothesis described which it is necessary to notice† is that which accepting George Darwin's conclusion that geologic time has witnessed a notable shortening of the equatorial diameter of the earth, with a corresponding lengthening of its polar diameter (an extremely questionable inference)—finds in this change of figure a "surplusage," and consequent shrinkage of the crust. The readjustment of the crust to the less flattened spheroid involves not only a diminution of its area, but the institution of a system of shearing and other strains calculated to wrinkle the surface in all parts except the Polar regions, and to produce what is actually observed—a maximum effect within the zone of the equatorial bulge. In the lunar tidal influence, the authors of this hypothesis find an independent reason for the prevailing meridional trend of the corrugations on the earth's surface. They see in the lagging of the tide a force tending to slip the tidal crust westwards; and this would result, during the ages of crust formation, in an ingrained meridional structure, which would in turn determine the trend of subsequent folds consequent on surplusage.‡ This ingenious "explanation" is, however, still *sub judice*. But it may serve to show how difficult it is to find a fitting solution of problems the terms of which have been stated in the dawn of creation, and to a large extent in a region which it is vain for any one less fortunate than the *voyageurs* of Jules Verne ever to reach.

The facts are, however, indisputable. The folding, crushing, and elevation of strata at one time lying flat at the bottom of the sea being visible and tangible, afford some solid material for the consolation of the geologist amid the perplexity of the themes which they have evoked.§

* "Hawaiian Volcanoes," p. 193; *American Journal of Science*, Vol. XXIII., p. 283.

† Mr. Fisher's idea of this elevation being due to expansion of the crust by fissures opening upwards from the liquid zone so often noticed, and filled with matter proceeding from it, is far too imaginative for a prosaic world of plain men.

‡ Winchell and Taylor: *Proceedings of the American Association for the Advancement of Science*, 1885. (Ann Arbor meeting.)

§ Suess: "Die Entstehung der Alpen" (1875); Heim: "Untersuchungen über den Mechanismus der Gebirgsbildung, etc." (1878), in which the structure of the Alps and other continental ranges is minutely described, and names, altogether superfluous, are applied to the different folds and parts of a fold in crumpled rocks; Mojsisovics v. Mojsvar: "Die Dolomitrisse von Südtirol und Venetien" (1879); the last chapter has useful remarks on this subject; Reade: "The Origin of Mountain Ranges" (1887), in which expansion by heat is invoked as the cause of mountain elevation; Powell: "Geology of the Uinta Mountains" (*Reports of the United States Geological and Geographical Survey*, 1876); etc.

CHAPTER X.

Geysers: Their General Character and Geographical Distribution.

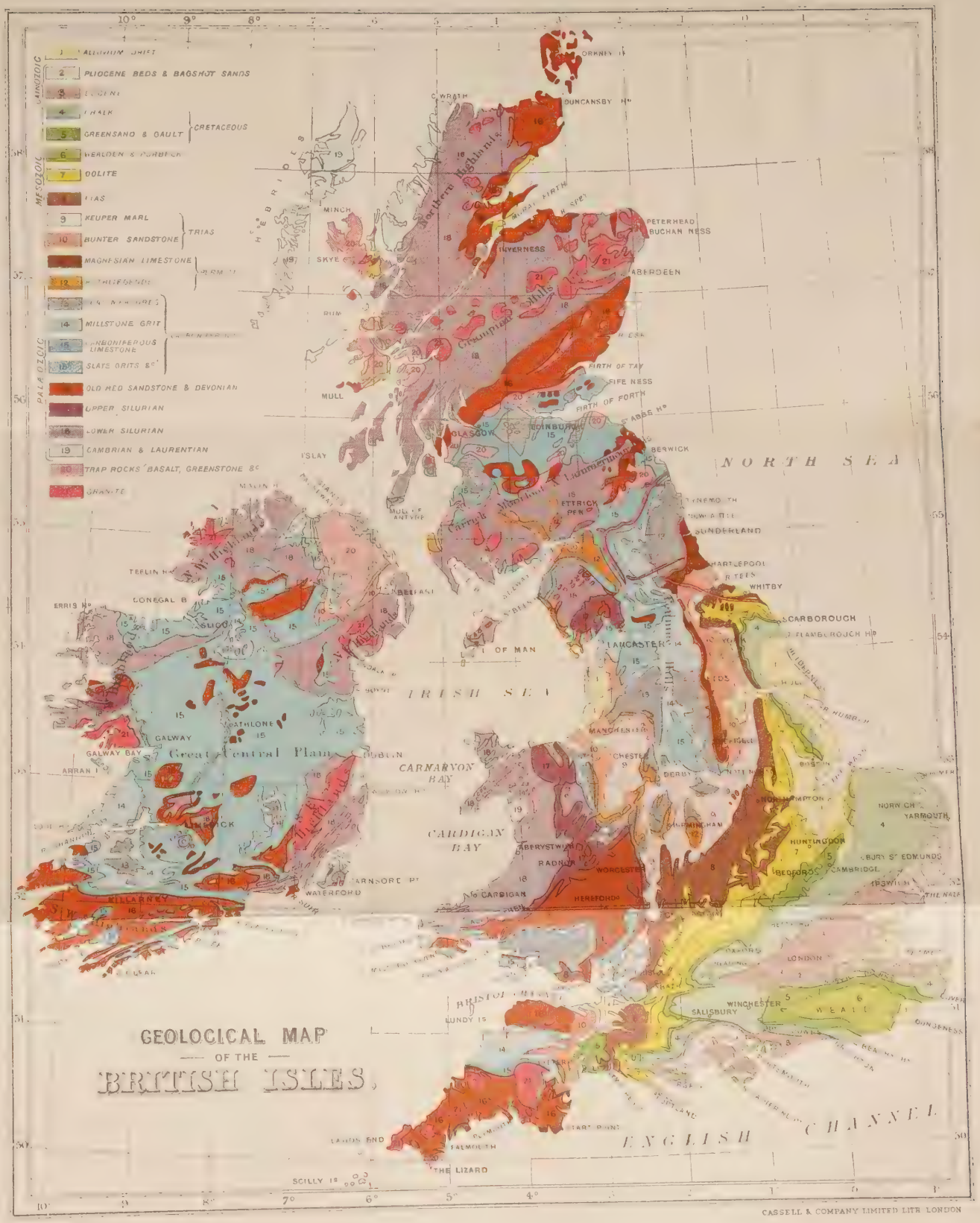
Geysers distinguished from Volcanoes—Their General Character and Mode of Action—Found in almost every Part of the World, though chiefly in Countries where there are active Volcanoes—Those of Iceland—Those of the Yellowstone Country—Description of the Principal Geysers of this Wonderland—A Few of Asia and Africa—Those of New Zealand—The Hot Lake Country—The Pink and White Terraces—The great Catastrophe by which they were destroyed and the entire Geyser System of New Zealand altered.

Whatever may be the force which sends the contents of the subterranean world to the surface of the crust on which we live—and, like "the songs which the Sirens sang," this force has not as yet admitted of more than an approach to "a reasonable solution,"—it acts not only on rocks, but on the other contents of the earth also. Water, we know, is discharged out of craters; but this water is, in all likelihood, only surface accumulations, or derived from reservoirs at no great depth. The steam we have already discussed, and the muddy stream which so often accompanies a volcanic outburst has been accounted for. But boiling water, mud, and various gases may be discharged from the earth under conditions almost identical with those which attend the discharge of lava. These emanations form some of the most interesting of displays, and, apart from their scientific importance, deserve consideration merely from a picturesque point of view. They are volcanic outbursts robbed of their destructive elements—eruptions to which no doleful memories attach.

General Character of Geysers.*

Geysers in their simplest forms are boiling fountains, which spout intermittently. They are invariably connected with volcanic phenomena, and are usually situated in a volcanic district, like that of the south-western division of Iceland, where, within a circuit of about two miles, upwards of one hundred are found. Few of them play more than five or six minutes at a time, and the intervals between their periods of repose and of activity vary so much that it has been stated at all times—from thirty hours down to eleven times daily for those of Iceland, and from twenty-five or more hours down to fifty minutes in those of the Yellowstone country in North America. The "Old Faithful" geyser in this region is so regular in its operations, and they occur so frequently, that they afford unusual opportunities for observation. It is in the centre of a mound or table, nearly twelve feet above the surrounding level, and formed of the geyserite, or loose, porous silica deposited from the water thrown up, this deposit being arranged in a succession of small steps which constitute a series of little basins. Near the top of these basins are beautiful broad, shallow pools, with pink, cream-white, brown, and grey bottoms, in which the deep azure-tinted water stands after an eruption. The crater through which the water is discharged forms a basin, at the bottom of which is an irregular orifice, the head of the geyser tube. The eruption begins with some preliminary splashes or spurts, from three to a dozen or more, like abortive attempts at eruption. These continue for about four minutes, becoming more and more powerful, when they are followed by a rapid succession of jets, which escape with a roar and soon attain the maximum height that is, about 130 feet. Clouds of steam accompany the water, and reach a much greater altitude. In a few seconds after the maximum

* This word—which has been variously translated gusher, rager, or roarer—is from the Icelandic *að gjósa*, to gush; such spouting springs having been first known in Iceland, where, indeed, some of the most remarkable and best known exist.



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is attained the column dies down, with occasional vigorous spurts. The water eruption is followed by steam, which soon comes out very gently, and finally dies away, leaving the crater basin empty. The water eruption, according to Dr. Peale's observations, lasts from four to five minutes, but the steam

Fig. 100.—THE GREAT GEYSER OF ICELAND.

period is indefinite. The wind causes a great variation in the appearance of the column, and the volumes of steam will sometimes rise 500 feet into the air. Rainbows play around this tremendous fountain, as the water which falls about the basin in showers of brilliants rushes steaming down the slopes to the neighbouring river.* The interval between two eruptions varies from 50 to 80 minutes: 65 is the average.

Every geyser has some peculiarities not found in its nearest neighbours. But in general terms the foregoing description applies fairly well to these spouting springs wherever found. All of them are intermittent; all of them shoot up water of a high temperature, which falls into a deposit-crusted basin, the forerunner of the discharge being a rumbling subterranean noise, which, in the case of the Great Geyser of Iceland (Fig. 100), has been likened to a distant firing of cannon, and in some instances the earth is slightly shaken. Then, after playing like an artificial fountain, the discharge of water ceases, and a column of steam, rushing up with amazing force and a thundering noise, terminates the eruption for a time. In Iceland, if stones are dropped into the crater they are immediately ejected; and now that it is found

* Peale, in Hayden's *United States Geological and Geographical Survey of the Territories of Wyoming and Idaho*, 1878, Part II., p. 221. This report is the most exhaustive monograph on geysers and their collateral phenomena in existence. It is the source of most of our information on the distribution of these fountains.

that by throwing a great quantity of large stones into the pipe of the geyser an eruption can be hastened, tourists have begun to adopt the practice of choking the throats of these fountains with stones—"an indigestible bolus," which, according to Professor Barrett, "often proves a fatal dose to a geyser." Then, as if the projecting force had been pent up, the stones and turf, as well as the boiling water, are thrown to a greater height than usual, though it has been noticed that the geyser, seemingly exhausted by the effort, does not achieve a fresh eruption after the lapse of the ordinary interval of rest. All of the water ejected by geysers contains more or less silica in some form, and, in the case of those in New Zealand, much common salt and other mineral and even metallic matter, which, when the water evaporates, remains behind in the form of flinty "sinter," or in sheets covering the adjacent country for several miles, and deposits itself along the margins of the basins in the shape of beautifully fretted rims, surrounding pools, which, when the hot springs issue on the side of a slope, give them the appearance of a terrace (coloured Plate, and Fig. 6 and Fig. 101); for though the term "geyser" is confined to spouting springs, it will be seen that the distinction between these and the unintermittent ones is not very well marked.

Geographical Distribution of Geysers.

Iceland.—The best known and in some respects the most interesting geysers and other hot springs are those of Iceland, though in extent they are rivalled, if not excelled, by those of New Zealand and the Yellowstone country in North America. The most important group of these is in the southern or south-western area, in which are placed the famous Haukadal Geysers. These are about fifty miles north-west of Mount Hekla, and comprise within a circuit of two miles one hundred or more hot springs, although the principal geysers are all within an area of a quarter of a mile by 300 feet. The chief of these are the Great Geyser, the Strokhr, and the Little Geyser. The Great Geyser is situated at the northern end of a plateau of deposits, and consists of the usual basin—like a saucer with a hole at the bottom of it—on the summit of a mound of silicious deposit, more than twenty feet in height. When the geyser is not in action, the water in the basin over the tube is in constant motion. Paijkull, by throwing bits of paper into the basin, showed that the hot water rising from the tube is drawn slowly towards the edges, when it sinks and flows back along the bottom of the basin, so that the temperature of the basin is a constantly shifting one. The steam from the geyser has an odour of sulphuretted hydrogen, and the water has also a slight, though only passing, taste of the same gas. The Great Geyser has two kinds of eruptions—in this respect resembling some of the Yellowstone spouters, especially the Union in the Shoshone Basin, and the Castle and Giant in the Upper Basin of Fire Hole River. After the minor eruptions the water does not sink, although their precursors are the same rumbling subterranean noises which herald the greater discharges. The former occur every hour and a half to two hours, and become stronger and more frequent as the period for a great upburst is approached. These minor upheavals—or "conical water hills," as Bunsen calls them—consist of a succession of jets, each jet attaining a greater and greater height, until the maximum is attained. After the eruption is over the column disappears from the basin and sinks about ten feet in the tube, only resuming its old level in the basin after an interval of from two to seven hours. The most common interval between the end of one and the beginning of another eruption is thirty hours—though eruptions sometimes occur every six hours,—the duration of the discharge varying from five to twenty minutes, the height reached by the column of water being stated at all elevations from forty to 360 feet; the mean may perhaps be taken at something over one hundred feet, while the temperature runs from 180° to 219°. Mr. Coles found that at a depth of 78 feet in the tube the temperature was 228°. "Subterranean noises

like thunder," Mr. Symington writes, in his account of an eruption of this geyser, "were waxing louder and louder, each earth-shock accompanied by a tremor of the ground, more or less violent, but quite unmistakable. Bells of water in quick succession were rising from the basin, and falling again, ever increasing in size, till a large one outburst; and then jets of water in successive spurts rushed up in sheafs from the tube: at first about 10 feet, then the height was 15, 20, 30, 50 feet, and so on, each effort surpassing the preceding, till it attained the height of 200 feet. The fountain did not fall down between each jet, but, nearly holding the elevation once gained, the whole grew up bodily by a series of jerks, each higher than the last. Dense clouds of steam enveloped the whole, and only afforded occasional glimpses of the columns of water from the leeward side. White vapour also spread out above the fountain, rolling away in vast curling volumes, which, condensing in the air, came down like heavy dew. Tremendous sounds were continuously heard, like the roaring of an angry sea, broken in upon by the near discharge of minute guns. It is at last a grand eruption of the Great Geyser! The vast body of water from the central pipe continued jetting up till, as I have said, it attained the height of 200 feet, falling down again into the basin, which was brim full to overflowing. The subterranean rumbling sounds and reports, accompanied with vibrations of the ground, were fearful. Jets of water rushed up in sheafs with a continuous noise, such as would be produced by 500 rockets discharged into the air at the same instant. The eruptive forces having now expended themselves for a time, the fountain gradually subsided in the same manner, though more speedily than it had risen. The whole terrific spectacle lasted about twenty minutes. We were singularly fortunate, as, from what we were told, few eruptions of late (1861) have lasted more than four or five minutes, or attained half the height of this which we had just witnessed."

Before 1789, the Strokhr—or churner—was an inconsiderable spring, the name being at that date applied to another geyser, which has since then become a quiet spring. Unlike the Great Geyser, from which it is distant 120 yards, the Strokhr has no regular basin: the tube gradually narrows from a diameter of 9 feet at the surface to 10 inches at 27 feet below the surface. In this funnel-shaped tube the water is usually from 9 to 10 feet below the surface, and is generally at or near the boiling-point all the time, being in a state of constant ebullition except just before an eruption, which begins without any premonitory detonations, as is the case of the Great Geyser. There is an interval of from six to twelve hours between the eruptions, which can be hastened by choking up the tube with turf and stones, this plug preventing the disengagement of the steam, and increasing the pressure which finally removes the impediment with a sudden force. The height to which the column rises has been estimated at from 40 to 162 feet, while the duration of an eruption is rarely over one hour. The Little Geyser spouts only from 10 to 20 feet about every two hours, and the Roarer, which, previous to 1789, even rivalled the Great Geyser, gradually diminished after the earthquake of that year, and finally ceased to spout, a fact of some importance in considering the cause of these eruptive fountains of hot water.

Yellowstone Region.—A geyser country even more remarkable for the size and the number of its spouting fountains is the Yellowstone region in the north-west part of the Territory of Wyoming in the United States, which, by a special Act of Congress, has been reserved as a National Park, exempt from settlement, purchase, or pre-emption. Here nearly every form of geyser and unintermittent hot spring occurs, with all the silicious and other deposits from them. Of the latter, Dr. Peale—to whom we are indebted for nearly all of the facts relating to this section of our subject—enumerates 2,195, and considers that within the limits of the park—which is 55 miles by 65 miles, and includes 2,288,000 acres—as many as 3,000 actually exist. The same geologist

notes the existence of 71 geysers in the area mentioned, though some of the number are only inferred to be spouting springs because of the form of their basins, and the character of the surrounding deposits. Of this vast collection of still and eruptive springs, between which there seems every gradation, those which do not send water into the air are, owing to the magnificent cascades which they form (Fig. 101), often quite as remarkable as those which take the shape of geysers. A few of the latter may, however, be briefly noticed.

In the Gibbon Geyser Basin is one which has broken out within a short period. In 1878 this geyser consisted of two steam holes, roaring on the side of a hill, that looked just as if they had burst through the surface; and the gully leading towards the ravine was at that date filled with sand, which appeared to have been poured out during an eruption. Dead trees stood on the line of this sand floor, and others with their bark still remaining, and even with their foliage not lost, were uprooted hard by, everything pointing to the "steamboat vent," as it was called, having been of recent formation. In 1875 it had no existence, but in 1879 this geyser, which first opened, it is believed, on the 11th of August in the preceding year, had "settled down to business as a very powerful flowing geyser" with a double period, one eruption occurring every half hour, and projecting water to the height of 30 feet, the main eruption occurring every six or seven days, with long-continued action, and a column of nearly 100 feet.

The New Geyser in the same basin is also of very recent origin. It consists of two fissures in the rock, in which the water is boiling vigorously. But there is no mound, and the rocks of the fissure are just beginning to get a coating of the silicious geyserite deposited from the water, so that it cannot have long been spouting. Again, in the Grotto Geyser, in the Upper Geyser Basin of Fire Hole River (Fig. 102), the main or larger crater is hollowed into fantastic arches, beneath which are the grotto-like cavities—from which it is named—which act as lateral orifices for the escape of water during an eruption. It plays several times in the course of the twenty-four hours, and sends a column of water 60 feet high, the eruption lasting an hour. As yet, however, the force of the water has not been sufficient, or of sufficiently long duration, to break through the arches covering the basin or crater. The Excelsior—now claimed to be the largest of its order, which sends water 300 feet into the air at intervals of about five hours, and of such volume as to wash away bridges over small streams below—was not, until comparatively recent years, known to be the powerful geyser it is. But if it had for a time waned in importance, its immense crater, 330 feet in length, and 200 feet at the widest part, shows that at a still earlier date it was a gigantic fountain. In this deep pit, when the breeze wafts aside the clouds of steam constantly rising from its surface, the water can be seen seething 15 or 20 feet below the surrounding level. Yet into the cauldron of boiling water a little stream of cold water, from the melting snow of the uplands, runs unceasingly.

The Castle Geyser is so named on account of the fancied resemblance which its mound of white and grey deposit presents to the ruins of a feudal keep, the crater itself being placed on a cone or turret, which has a somewhat imposing appearance compared with the other geysers in the neighbourhood. It throws a column usually about fifty or sixty feet high, at intervals of two or three hours, but sometimes the discharge shoots up much higher. Lord Dunraven, indeed, reckoned the column which he saw to measure fully 250 feet, though as the eruption is accompanied with a voluminous discharge of steam which reaches much higher than the water, it is possible that this observer over-estimates the height to which it attained.

The Giant, in the Upper Geyser Basin, has a peculiar crater, which has been likened to the stump of a hollow sycamore tree of gigantic proportions, whose top has been wrenched off by a storm. This curious cup is broken down at one side, as though it had been torn away during an eruption of more

Fig. 101.—MAMMOTH HOT SPRINGS OF GARDINER'S RIVER, YELLOWSTONE NATIONAL PARK, NORTH AMERICA, WITH TERRACES OF TRAVERTINE OR CALCAREOUS TUFA. (*After a Photograph.*)

than ordinary violence, and on this side the visitor is able to look into the crater, if he can contrive to avoid the jets which are constantly being spouted from it. The period of rest which it takes is varied, an eruption not occurring often for several days at a time, and then, when it breaks out, it continues playing for more than three hours, with a column of water reaching a height of from 130 to 140 feet, though, as we have seen, little spouts are constantly in progress. Mr. Stanley saw one eruption which he calculated to have shot a column of water to the height of more than 200 feet. At first it seemed as if the geyser was only making a feint, the discharge which preceded the great one being merely repeated several times, followed by a cessation both of the rumbling noises and of the ejection of water. But soon, after a premonitory cloud of steam, the geyser began work in earnest, the column discharged, rising higher and higher, until it reached the altitude mentioned. "At first it appeared to labour in raising the immense volume, which seemed loath to start on its heavenward tour; but it was with perfect ease that the stupendous column was held to its place, the water breaking into jets and returning in glittering showers to the basin. The steam ascended in dense volumes for thousands of feet, when it was freighted upon the wings of the wind and borne away in clouds. The fearful rumble and confusion attending it were as the sound of distant artillery, the rushing of many horses to battle, or the roar of a fearful tornado. It commenced to act at two P.M., and continued for an hour and a half, the latter part of which it emitted little else but steam rushing upwards from its chambers below, of which, if controlled, there is enough to run an engine of wonderful power. The waving to and fro of such a gigantic fountain when the column is at its highest,

"'Tinselled o'er in robes of varying hues,'

and glistening in the bright sunlight, which adorns it with the glowing colours of many a gorgeous rainbow, affords a spectacle so wonderful and grandly magnificent, so overwhelming to the mind, that the ablest attempt at description gives the reader who has never witnessed such a display but a feeble idea of its glory. Our entire party were perfectly wild with enthusiasm. We could not suppress emotion, but shouted and cheered till out of breath, and some fired guns and revolvers in the air, so great was their excitement in the midst of such a display. Every person in the basin—thirty-four in number—was soon on the ground, and lawyers, judges, professors, farmers, merchants, miners, and philosophers, were alike filled with enthusiasm by the magnificent spectacle. A perfect river of water, equal to the volume of the Fire Hole, rushed down the slope; and in our excitement to get a view from every point of vision, we several times slightly tested its temperature by a mis-step, landing us half-way to our boot-tops in the steaming flood. Every one thought the column 250 feet high, though we had no means of measuring it." *

The only other geysers in this remarkable geyserland which we can spare room to notice are those known as the Giantess, the Beehive, and the Grand. The Giantess sends a column of water to the height of 250 feet. An eruption is usually divided into three periods—two preliminary efforts and a final one, divided from each other by intervals of between one and two hours, while the intervals between the periods of discharge are very long. Sometimes it does not play for several weeks. The Beehive, which is 400 feet from the Giantess, gets its name from the peculiar beehive-like cone which it has formed. The eruption is also almost unique. It is heralded by a slight escape of steam, which is followed by a column of steam and water, shooting to the height of over 200 feet. The column is somewhat fan-shaped, but it does not fall in rain, the spray being evaporated and carried off as steam, if, indeed, there is not more steam than water in the column. The duration of the discharge is between four and five minutes,

* Stanley: Rambles in Wonderland" (1878), pp. 114, 115; Dunraven: "The Great Divide," p. 273; Comstock, in Jones's "Reconnaissance of North-West Wyoming in 1873," p. 25.

and the interval between two eruptions from twenty-one to twenty-five hours.

The Grand is one of the most important in the Upper Geyser basin. Yet, unlike the Grotto, the Giant, or the Old Faithful (p. 192), it has no raised cone or crater, and a much less cavern-like bowl than the Giantess and other geysers. The column discharged ascends to the height of from 80 to 200 feet, and the eruptions last from fifteen minutes to three-quarters of an hour, with intervals on an average of from seven to twenty hours. This fountain is evidently very irregular in its action, though it is just possible that when the Yellowstone geysers have been more consecutively studied, it will be found that these seeming irregularities depend on the varying supplies of water at different times of the year.

The Yellowstone National Park is, indeed, a region of thermal waters of every description. Scarcely a foot of the 3,575 square miles of the area is not honeycombed by active, passive, or extinct fountains of this description, or covered by the fantastic and often lovely concretions formed by the silicious and calcareous deposits from these boiling waters which rise to the surface. Steam rises out of the soil in the most unexpected places, and the pedestrian has to tread warily lest, when he least expects it, the ground will subside under his feet, and, by the crushing of the thin crust, he be precipitated into a boiling pool or bubbling cauldron of mud. It is truly a "wonderland." Yet in all this region there is not one volcano, either active or extinct, since the arguments for believing that Mount Washburne is an old crater are very fragile. The National Park, therefore, differs from Iceland, where the geysers are in near proximity to active volcanoes, and New Zealand, where, as we shall presently see, the geyser region is also one of busy volcanic energy.

Other Parts of America.—The Yellowstone country is, however, not the only geyser land of America. Hot springs are found in the Appalachian region, in Arkansas, and in the country west of the 105th meridian in far greater abundance than in either of the other divisions. In the basin of the Mississippi River, and on the plains east of the Rocky Mountains, there are no thermal springs—a fact which has not been lost sight of by those theorists who attribute the heat to which they owe their origin to mountain corrugation. Outside of the National Park the greatest development of hot springs is in California and Nevada, though they are not wanting in the region north of those States, several being found in British Columbia, at Banff, in the North-West Territory, where a Canadian National Park is to be formed, and, it is said, in Alaska, though we are not aware of any existing in Vancouver and Queen Charlotte Islands, or in the coast region of British Columbia and the country immediately south of that province. Spouting springs are, however, less frequent. In California the geysers are chiefly in Napa Valley, north of San Francisco, where, in a cañon or defile, covered with deposits of extinct fountains, there are numerous steam jets and hot springs, some clear, some turbid, some chalybeate, some sulphurous, and some impregnated with alum. This ravine is always thick with the steam rising from these jets, or from basins like the "Witches' Cauldron," which is in a constant state of ebullition. The Steamboat Geyser discharges steam to a height of from 50 to 100 feet, with a roar like the escape from a steamer. But few of the fountains in this cañon are regular geysers—most of them only discharging steam, or in exceptional cases throwing up water to the height of two feet, or even as high as fifteen or twenty feet.

The Steamboat springs in Washoe Valley, east of the Virginian range in Nevada State, are more of the nature of the Yellowstone Park geysers, the deposit from their waters being true geyserite, though in no case is water or steam ejected higher than from ten to twenty feet.

The Volcano Springs in Lander county, in the same State, are true geysers, though of small importance. The ground in their vicinity is described as being so perforated by orifices through which steam escapes that

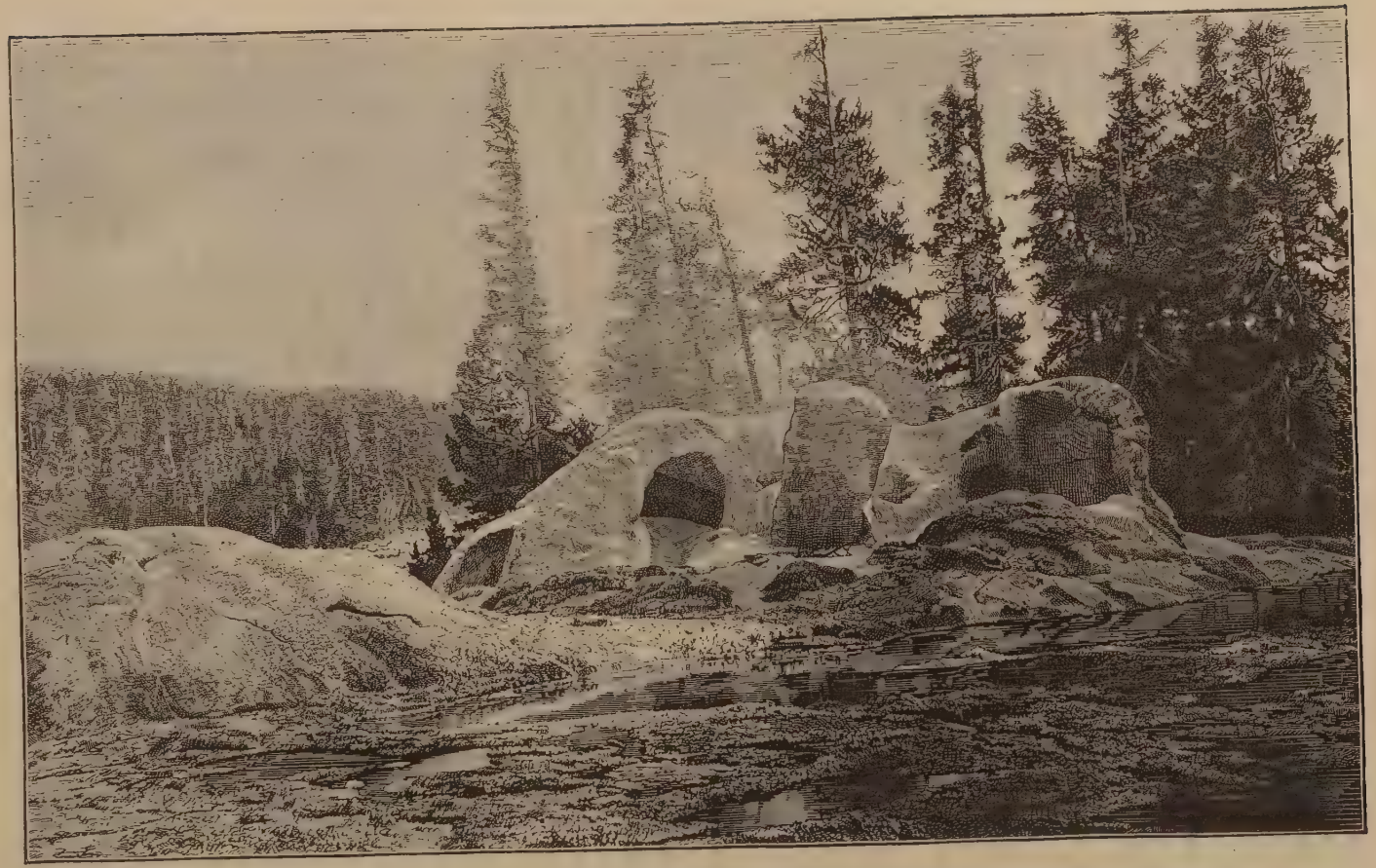


Fig. 102.—THE GROTTO GEYSER IN THE UPPER GEYSER BASIN OF THE YELLOWSTONE NATIONAL PARK.

(*After a Photograph.*)

it looks like a cullender. In Mexico there are endless hot springs, the distribution of which corresponds, as does that of those in Central America, with the range of the volcanoes.* However, at Aguas Calientes, not far from San Luis Potosi, there is a geyser; but though there are many boiling springs, and even boiling in Bolivia they are innumerable; in Chili and Ecuador they are found in every shape and of all compositions; in Brazil there are many; and even in Patagonia there are several. But true geysers have still to be discovered in that continent.

Africa and Asia.—In like manner, though

Fig. 103.—MUD VOLCANOES AT TURBACO, IN THE UNITED STATES OF COLOMBIA, SOUTH AMERICA.

lakes—like that in the Grand Soufrière of Dominica—no true geysers are known in Central America or in the West Indies, unless, indeed, the lake just mentioned is to be classed as one. It is a seething cauldron, 2,400 feet above the sea-level, and in its widest diameter 600 feet, with no bottom at 195 feet. It is in an active state of ebullition, especially in the centre, the water being thrown into jets at intervals. In South America there are plenty of thermal springs; thermal springs are numerous on continental and insular Europe—England included—and in the Azores, Africa, and the islands of the Indian Ocean, they are none of them of the spouting description, unless we except the Caldeiros or boiling fountains of the Azores, some of which spout to the height of twelve feet, and deposit large quantities of sinter of the usual description. In Tibet there is an interesting geyser and hot spring locality, near Lake Namcho or Tengri Nor, in which are fountains which shoot to the height of forty or

* Judd: "Volcanoes" (1881), p. 227.

fifty feet, with a noise so great that during the discharge they drown the voices of men. Similar jets issue from the middle of the adjacent River Lakú chu, and most probably many other geysers exist in this high plateau of Central Asia. Thermal springs are numerous in Japan, Formosa, the Malay Islands and Peninsula, Australasia, and Polynesia. Japan is said to have veritable geysers, though those hitherto described scarcely deserve that name, and pseudo-geysers are also found in the island of Formosa. In Celebes, however, geysers of the ordinary character exist on the Peninsula of Minhassa, though not of a character so remarkable as to deserve a lengthened description. Indeed, the eruptions of the one at Nolok are not periodical, the ejection of water occurring only at certain seasons and under peculiar circumstances. There are, however, various mud volcanoes which, as we shall see presently, may be regarded as geysers, from which mud, instead of water, is ejected (Fig. 103). Near Dempo Volcano, in Sumatra, there is in a crater a lake of seething mud, which Mr. Forbes describes as being "swallowed up and vomited forth once in every fifteen to twenty minutes," the contents being quiety ejected to the height of "some hundreds of feet."

New Zealand.—The Northern island of New Zealand is a geyserland only second to that of the Yellowstone; for though its spouting fountains are not so remarkable as those of Iceland, the beauty of their sinter-lined basins and of the terraces similar to those on Gardiner's River (Fig. 101), which, until recently, were the great sights of the colony, gave that part of the world a claim to distinction which Iceland does not possess. All of the "Lake region," as it is called, from the presence within this area of Taupo, Tarawera, Rotorua, Mokoia, Rotomahana, and other sheets of water, is a region of even more intense volcanic action than those described. For not only are geysers, hot springs, mud pools, etc., present, but earthquakes are not unfrequent, and the entire country is studded with active and extinct volcanoes. Whaakari, or White Island, in the Bay of Plenty, the nearest portion of the seaboard to it, is a submerged volcanic cone 860 feet high, out of the broken-down crater of which various volatile emanations are constantly proceeding, and at times with great activity. At one period it must have been a volcano of the usual order, but in the course of time it has become exhausted, and is now in what is known as the "Solfatara" stage. In its vicinity are geysers and boiling springs, which at all times evolve volumes of steam and sulphurous gas, to the latter of which are due the sulphur beds now worked on the island. Its entire area is covered with silicious sinter, and Lake Hope, occupying an area of fifteen acres, is an acid geyser lake of the temperature of 110°. From one part of this lake, Sir James Hector describes water spouting to the height of 100 feet. This island lies in the line of active thermal action, which stretches across the North island to Mount Tongariro, a distance of about 150 miles, the average breadth of the volcanic belt being about 40 miles. About 80 miles inland the hot lakes country is reached. Here we find a region elevated 1,000 to 2,000 feet above the level of the sea, and in its physical features embracing far-stretching pumice plains, "intersected in every direction by high ranges of igneous formation, which are relieved here and there by enormous volcanic cones," varying in height from 1,000 to 9,000 feet. "Extensive forests of extraordinary luxuriance and beauty clothe the mountains and border the extensive plateaux, while hot lakes, boiling geysers, and thermal springs are dotted far and wide over the country."

The lovely Lake Rotorua is everywhere bordered by distinct traces of fire and water combined, in the shape of silicious and sulphurous deposits, the result of the hydrothermal action of the all-abounding geysers, hot springs, mud-holes, solfataras, and fumaroles—or points at which volcanic vapours are copiously discharged—with which the country is riddled. Lake Rotoiti is of much the same character, while the waters of the warm lakes, known as Rotoma and Rotoehu, are rendered of a greyish opaque colour by the action of

subaqueous springs. Lake Tarawera, with its cluster of minor lakes, is right in the centre of this zone of volcanic activity. On its southern shores Mount Tarawera—a truncated volcanic cone 1,964 feet high—is situated, its summit, until the outburst of 1886, being a sort of tableland, divided by crater-like ravines, showing that it must have long been quiescent. On the western side of Tarawera a range of conical volcanic hills stretches to the shores of Lake Rotomahana, surrounded by hot springs, and, until 1886, by the wonderful Pink and White terraces (p. 16), formed by the silica-laden water of the neighbouring geysers. The water of the lake, owing to the many hot springs, was always of a high temperature. "Every bend of the shore and jutting point of land," Mr. Kerry-Nicholls tells us in his admirable account of this country, "was alive with its cluster of steaming fumaroles; every valley sent up its cloud of steam, and echoed to its fountains of heated waters; while the quaking soil and smoking hills sent forth their jets of vapour and sulphurous fumes from a thousand fissures" (Figs. 104, 105).

Fig. 104.—STEAM GEYSER OF KARAPITI, IN NEW ZEALAND.

Southward from this lake, boiling pools and deep holes filled with bubbling mud extend to the Paeroa Mountains, which, during the outbreak of Mount Tarawera, assumed an extraordinary activity, new craters bursting forth, and clouds of steam ascending from their highest peaks. The central volcanic region extends from the Paeroa Mountains to a region southerly to Mount Ruapehu, one of the largest extinct craters in the world. At the native village of Orakei-korako, in the winding valley of the Waikato River, countless steam jets, hot springs, and geysers, bubble and hiss above the sparkling waters of the stream, the banks of which are fringed with clustering masses of pure white silica and other deposits from the fountains, of which the traces or actuality are everywhere present. At Wairakei, in the same valley, the hot springs, geysers, fumaroles, and solfataras, cover more than 4,000 acres. This spot is, to use the language of Mr. Kerry-Nicholls, "one of the most marvellous creations of its kind to be found in any part of the world. It forms one of the principal arteries of hydrothermal action traversing the country. The bottom of the valley is situated at an elevation of 1,000 feet above the sea, while down its centre a warm stream of water flows rapidly on its course to join the Waikato. Its steep sinuous sides rise in some places to a height of 200 feet. Looking down the valley, one sees the winding course of the great fissure filled with a dense growth of vegetation forced into vigorous life, as it were, by the white clouds of steam that mount into the air on every side from the great geysers and innumerable boiling springs. Every geyser spring and mud-hole has its clustering vegetation, and gazing anywhere up and down the valley each thermal wonder bursts upon the view with a fresh and startling beauty. The warm stream which gathers its waters from the overflowing geysers and springs is in some places entirely fringed with

silicious deposits, some white and beautiful, like overhanging folds of lace, some dipping down into the water in the form of enormous stalactites, while others, assuming a buttress-like formation, are green with ferns and dank mosses of a varied hue. When the thermometer was inserted about a foot beneath the soil, and right under the very roots of the moss, it rose rapidly to 210°. Not far distant from this valley a remarkable

Fig. 105.—BOILING SPRINGS, FUMAROLES, AND GEYSERS ON THE WAIKATO RIVER, NEW ZEALAND.

spring takes its rise in a small, warm lake. Along its course at various intervals are small cascades, which, falling into broad basins, form natural baths. The efficacy of this water for curative purposes has been long known to the Maoris, who give it the name of *Kiriohniekai*, or 'new skin,' from the singular properties which it possesses in the cure of cutaneous and rheumatic disorders. The water in colour is of a bluish-green, is pleasant to the taste, and when taken inwardly quickly produces a very strengthening effect upon the system. We found that our horses drank readily of the water, even when in its warm state, which gave a temperature of from 90° to 150°. A short distance from the spring is a large fumarole of superheated steam which, issuing from the earth with a loud screeching noise, indicated 220°. From Wairakei it is about six miles to Lake Taupo, and along the winding course of the Waikato numerous clusters of fumaroles and hot springs stud the banks of the stream (Fig. 105), while one or

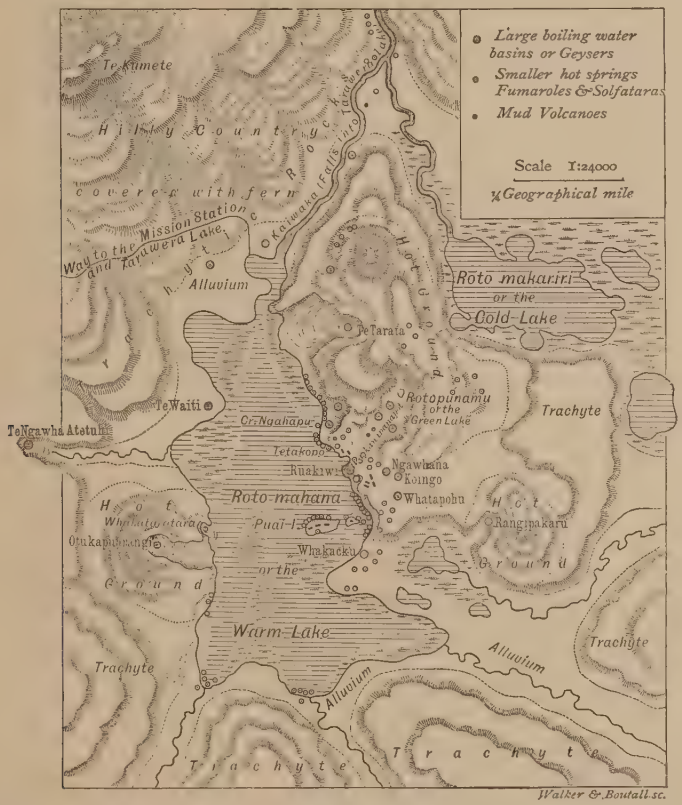


Fig. 106.—ROTOMAHANA, OR THE WARM LAKE, WITH THE NEIGHBOURING HOT SPRINGS.

(*After a Survey by Ferdinand v. Hochstetter in* 1859.)

two powerful geysers occur within a short distance of the shores of the lake."

The basin of Lake Taupo, in the centre of a table-land about 2,000 feet above the sea-level, seems to have been at one time the crater of a volcano, of a date prior to the origin of Ruapehu and Tongariro. The lake is of enormous depth, and its waters during the outbreak of 1886 were affected by tidal

waves which poured with some violence into the valley of the Waikato. The village of the Ngatiluwharetoa tribe of Maoris, on the extreme southern end of the lake, is built amid boiling fountains, hot springs, and fumaroles, in sight of the volcanic peaks of Tongariro and Pihanga. Tongariro rises from a cluster of trachytic cones, about fifteen miles south of this curious village. When Mr. Kerry-Nicholls ascended it in 1882 it was a very active solfatara; hot springs and geysers sent up streams of boiling water out of the crater; miniature cones of dark, smoking mud rose up in every direction; while around was what this traveller describes as "a seething, fervid mass of almost molten matter, which appeared to require just one or two degrees more of heat to transform it into a lake of liquid lava." In 1881 it showed signs of activity; and in 1886 it is said to have been obscured by a dense cloud of steam and smoke. Five miles distant stands Mount Ruapehu, in the centre of a great table-land. It also is an enormous truncated cone, with a base about sixty miles in circumference. It has long been extinct, though the vast deposits of scoriæ and lava in its vicinity tell a tale of immense activity at some period in its history. The rivers taking their rise in this mountain are white with sulphur and other deposits, which they cut through in their swift course to the lowlands.*

Of the numerous spouting fountains thus briefly noticed, one of the most remarkable was Ngahapu, at the back of what was until lately known as Te Tarata, or the White Terrace, close to Rotomahana, or the Warm Lake (Figs. 106, 107),† which, after boiling up in huge hot waves that "lashed themselves into fury against the rugged sides of the caldron with a loud hissing noise," shot a column of boiling water to a height of from ten to sixty feet. The crater was, however, always overflowing, and the water, charged with large quantities of silica, had by a gradual process of deposition formed the famous system of terraces. The natives declared that the geyser was most active during a prevalence of easterly winds, and that with a south wind the water receded.

What was known as Otukapuarangi ‡ (Fig. 6, and Fig. 106), or the Pink Terrace, was on the opposite side of the lake from Te Tarata. The geyser supplying it was smaller than that of Te Tarata. Its basin was very deep, and filled with azure-tinted water, which was generally boiling at a temperature of 204° to 208°. At times the geyser quieted down, and the overflow ceased, though the rate of interval between its active and passive periods has never yet been determined. In many respects the terrace formed of pools lined with beautiful silicious incrustations was like the White one, only that the fifty terraces were tinged with pink, which was most marked in the upper part of the deposits. The pink hue was due to oxide of iron; but, unlike Te Tarata, the deposits were "narrower at the bottom near the lake, on account of being enclosed in a horseshoe curve of the hill." Te Tarata (the tattooed rock or stone) was about 250 yards back from the edge of the lake, and 80 feet above it (*see* coloured Plate). Altogether it occupied over three acres. There was an upper platform, below which was the deposit in three sections, namely, "a central mass of two wings, separated from each other by clusters of foliage growing upon natural soil. Below these, however, the deposits were again united. The central section was the oldest, and had overhanging buttresses and terraces rising tier above tier. The right wing was an irregular slope broken into steps at several points, without any regular basins; and the left wing, over which the most ancient overflow found its way, was much like the right wing. Ridges and slopes, rather than basins and terraces, were formed."

* Kerry-Nicholls, in the *Times*, Aug. 5th and 11th, 1886; and "The King Country" (1884).

† In the Maori language the word "roto" means "lake." Hence Roto-rua, "lake number two;" Roto-ma, "white lake;" Roto-punamu, "green lake;" Roto-eha, "muddy lake;" Roto-makariri, "cold lake;" etc. The term "ngawha" is employed to designate non-intermittent springs and solfataras. "Picca" is a geyser or geyser-like fountain; while, according to Mr. Kerry-Nicholls, "waiariki" means a spring suitable for bathing.

‡ The meaning of the name is "cloudy atmosphere."

Immense clouds of steam played over the basin which supplied the material out of which this terrace was composed. These clouds of steam, while reflecting the beautiful blue of the basin generally, so obscured the water that it was only at intervals that it could be seen. But the loveliest portion of Te Tarata was what resulted from the deposition of the silica from the waste water of the geyser as it flowed down the slope to the lake. These incrustations formed on the face of the hill a system of terraces which—as Dr. Ferdinand v. Hochstetter, writing in 1863, put it—looked as white as if cut from marble. They presented the appearance of a "cataract plunging over natural shelves, which, as it falls, is suddenly turned into stone. The flat spreading foot of the terraces extends far into the lake. There the terraces commence with low shelves, containing shallow water basins. The farther up, the higher grow the terraces —two, three, also some four and six feet high. They are formed by a number of semicircular stages, of which no two are of the same height. Each of these stages has a small raised margin, from which slender stalactites are hanging down upon the lower stage, and which encircles on its platform one or more basins resplendent with the most beautiful blue water. These small water basins represent as many natural bathing-basins, which the most refined luxury could not have prepared in a more splendid and commodious style. The basins can be chosen, shallow or deep, large or small, and of every variety of temperature, as the basins upon the higher stages, nearer to the main basin, contain warmer water than those upon the lower ones. Some of the basins are so large and so deep that one can easily swim in them. In ascending the steps, it is, of course, necessary to wade in the tepid water, which spreads beside the lower basins upon the platforms of the stages, but rarely reaching above the ankle. During violent water-eruptions from the main basin steaming cascades may occur; at ordinary times but very little water ripples over the terraces, and only the principal discharge on the south side forms a hot, steaming fall. After reaching the highest terrace there is an extensive platform, with a number of basins five to six feet deep, their waters showing a temperature of 90° to 110°. In the middle of this platform there arises, close to the brink of the main basin, a kind of rock island, about twelve feet high, decked with 'manuka,'* mosses, lycopodium, and fern. It may be visited without danger, and from it the traveller has a fair and full view into the blue, boiling, and steaming caldron."

Those who have seen these terraces—they no longer exist—vie with each other in praise of their beauty. Some of these descriptions, indeed, partake of the rhapsodical. The chaste design; the unique, delicate beauty; the sublime detail of construction; the fairy-like scene—are all enlarged upon; while the sparkling water, glittering in the sun as it rippled over the marble-like terraces formed by itself, gave the entire slope the appearance of some enchanted palace decked with diamonds and myriads of other precious stones. At Orakeikorako, on the Waikato River, geysers are so numerous that Hochstetter counted seventy-six jets of steam or water from one point of view, the principal fountain spouting every two hours to a height of twenty or thirty feet, the eruption lasting two minutes, and the basin refilling ten minutes after the eruption is over. In the "Alum Cave" there is a beautiful blue pool of warm water. Near Rotorua, which has near its centre a volcanic island, and is probably one of those crater lakes on which we have had so much to say (pp. 132—139), the Wakiti geyser, which discharges through the centre of the usual cone built up of silicious deposits, is said to throw a column of water to the height of eighty or one hundred feet. Ordinarily, it spouts every eight minutes, though its great eruptions are reserved for special occasions, regulated, it would seem, by the condition of the atmosphere or the direction of the wind. Sometimes it will suddenly become active, and continue so for several weeks, each eruption excelling its

* The Maori name for *Leptospermum scoparium*, the New Zealand "tea-tree."

predecessor, and then just as suddenly subsiding.

There are several other geysers, but as they partake of much the same character, though of less moment from a scenic point of view, it is unnecessary to describe them. Indeed, the whole hot lake district of New Zealand is riddled with geysers in their varieties of mud-holes, boiling springs, solfataras, and fumaroles, and in places it is dangerous to tread the hot soil incautiously, lest the pedestrian be suddenly plunged into some seething mud-hole, or other evidence of the all-abounding volcanic force beneath (Fig. 106). Dr. v. Hochstetter, the Austrian geologist who surveyed the district about a quarter of a century ago, warned the people of the country that some day the shell might give way, though even he considered the volcanoes of the region to have expended themselves, and to be rapidly reverting to the extinct condition of so many others in that part of the world. In those days, however, there was almost no one, except Maoris, in the Lake District. But of late years it has been a favourite tourist haunt, and, still later, a sanatorium has been established for the benefit of those who wished to avail themselves of the healing virtues of the hot baths. Certainly in June, 1886, little apprehension of any coming disaster was entertained. Tongariro is always uneasy, but there had been no eruption since July 6, 1871, when flames and the noise of explosions issued from its crater; while Ruapehu, covered with a snow cap of dazzling whiteness, had never, so far as Maori tradition extends—and it reaches back for at least 1,000 years—been in actual eruption. But in 1881 it was noticed that the waters of Tarawera Lake became offensive, and for upwards of a year continued unfit for use; after which they resumed their accustomed purity. At Rotoiti, Rotoma, and Rotoehu lakes, distant sixteen miles from the principal point of the volcanic disturbance which was impending, the water was disturbed, and many new springs came into existence, while others disappeared about the same period. One boiling spring burst up in the native church during service, and in the Court House a geyser rose with such persistence that, Miss Gordon Cumming tells us, the building resolved itself into a bathing establishment, while the ground hard by gave way, engulfing a horse. This, however, was no extraordinary occurrence, for every now and then throughout this district a human being is swallowed up, or a child falls into a boiling spring. But even the Maoris had an idea that something uncommon was about to happen. A ghostly war canoe of the ancient type was reported to have been seen sailing up Tarawera, and new steam holes and pools appeared near the White Terraces, while others so rapidly increased in violence that the native guides began to lose themselves amid the constant change of the ground with which they were so familiar. Three years ago Rotokakahi—a lake the water of which had been always clear and cold—suddenly rose almost to boiling, throbbed convulsively, and assumed a disagreeable smell, as if sulphuretted hydrogen had been discharged into its waters. White Island, seventy miles distant, showed signs of redoubled activity; the sulphur miners had to leave it; clouds of red dust enveloped it; stones were ejected a thousand feet into the air, and the sea birds, which usually abound on its shores, were compelled to forsake them. Tongariro was several times in the spring of 1886 shrouded in smoke, though whether flames actually proceeded from its crater is not established, except by doubtful native testimony. The waters of Lake Taupo were not only affected by "tidal waves," but various minor shocks of earthquakes were felt around its shores.

On the night of June 10—11th, 1886, these premonitory symptoms ended in a catastrophe, the like of which New Zealand has not seen since the islands were settled by European colonists. The inhabitants were awakened by a "horrible roar" and the tumult of violent earthquakes. Simultaneously they beheld Tarawera crowned with flames, after which came "a deafening, continuous explosive roar, and another pillar of black cloud uprose, enfolding the fiery pillar in dense darkness, only relieved by appallingly vivid flashes and

Fig. 107.—ROTOMAHANA, OR THE WARM LAKE, NEW ZEALAND.

(*From a Photograph taken prior to the eruption of June*, 1886.)

sheets of lightning, but of a blood-red tint, resulting from the intervening dust clouds." This was accompanied by a terrific thunderstorm, and the sky was for hours lighted up by the lurid glare of lightning, while the atmosphere was poisoned by a suffocating sulphurous stench, accompanied by heavy showers of ashes, some of which fell on the sea-board forty miles away. Earthquake shocks, in the meantime, continued without intermission. In the course of a few hours seventy distinct tremors were counted, and until noon of the 11th the darkness continued. Then, when a gleam of light came, it was seen that the face of the country was covered with "white or grey ash, and that hundreds of new boiling springs had burst out in every direction, some throwing up blue boiling mud, and many were actually along the roads, rendering all travel a matter of serious danger." Panic naturally seized many of the inhabitants. They fled, not knowing in what direction to take refuge. Nor was the terror moderated by the tidings which gradually came dropping in. The flourishing settlement of Wairoa was destroyed and several lives were lost, many houses being thrown down by the earthquakes, or overwhelmed by the showers of ashes and mud, while others caught fire, and were consumed in the confusion. Mokoia, the island in the centre of Lake Rotorua burst into an eruption of steam, and hideous mud and sulphur banks appeared at Tikitere on the shores of Rotoiti, which is separated from Rotorua by a narrow isthmus, while tracts of country were covered with the pumice and ashes which formed the first portion of the discharge from Tarawera, or with the showers of mud which followed. The volcano itself was rent by two huge fissures, into one of which the drainage of the mountain has emptied, forming a new lake, absorbing and extending the little Lake Rotomakariri, while another little green-coloured lake filled a crater 75 yards in diameter. The borders of the fissures were coloured with ferrochlorides, and from the bottom of the great gorge, 200 yards in width, and 250 feet, formed in a single day, steam fumes of hydrochloric acid, and occasionally deep brown smoke, were seen to proceed when the mountain was ascended immediately after the great catastrophe described. There was no sign of lava. Indeed, the New Zealand volcanoes, in recent times at least, have contented themselves with ejecting nothing more serious than ashes and mud. But there were evidences that the convulsion of Tarawera consisted not solely in a displacement of the original constituents of the mountain, but in the ejection of rock in an incandescent condition. Scoriæ and volcanic bombs were plentiful. The force of the eruption must have been enormous, for the volcanic explosions opened not simply two or three small craters, but forcibly "expelled the whole centre of the massive three-peaked mountain or range for a length of two and a half miles to a depth varying from 400 feet to 1,400 feet."

Rotomahana had almost disappeared. The bed of the lake is now 500 feet below the old level, and is considerably lower than Tarawera, into which its surplus water formerly flowed. Indeed, with the exception of about an area 750 feet by 300 feet still covered with water, Rotomahana is now entirely composed of steam holes, several of them 150 feet across, and mud volcanoes, one or two of them 600 feet high and 300 feet across, belching forth mud and stones to a height of 100 feet or more. New geyser craters have broken out all around the lake, some of which, during the preliminary eruption to which they owe their existence, discharged blocks of stone fully 100 tons in weight.*

But to the sightseer the most lamentable result of the dismal work done on that fatal 10th of June was the destruction of the White and Pink Terraces. Several days elapsed before it was possible for the explorers to reach Lake Rotomahana. When, however, the place was neared it was discovered that these chief attractions of the district were numbered among the things that had been. "Where, but a few days previously, the wild fowl were swimming securely among the reeds

* Smith, in *Proceedings of the Roy. Geog. Soc.*, 1886, pp. 783—785; Geikie, in *Contemporary Review*, Oct., 1886.

and sedges which bordered the quiet lake," Miss Gordon Cumming tells us, in the interesting narrative from which we are quoting, "there now exists only a chaotic wilderness of cones and craters, all in hideous activity, ejecting clouds of pestilential black smoke and showers of stones. One large crater was in full action on the spot where the beautiful Pink Terrace had hitherto gladdened all visitors by its loveliness, and another, apparently close to the White Terrace, was throwing up masses of black dust and steam, which rose in columns thousands of feet in height. An artist was so eager to obtain a sketch of the scene that he narrowly escaped adding one more to the list of victims; for, a moment after he had left the brink, the whole ground where he had stood slid down bodily into the crater. The roaring of the steam rising from the chasm between the Pink and White Terraces was appalling, and the sulphurous stench suffocating. Every now and then a more deafening booming accompanied a violent explosion, shooting up liquid mud. One such shower, starting from a base about two hundred yards long, was shot up perpendicularly to a height of several hundred feet, falling in seven separate tapering columns."

Serious as was the loss of life, it might easily have been more. A rash speculator had actually made all arrangements for building a hotel on the brink of the Pink Terrace. The licence was taken, and the ground for the site prepared. Had the eruption been delayed—or the building been expedited—by a few months the hotel would have been crowded with travellers. In the Yellowstone country a large hotel is erected upon a great geyser terrace, and a dormant water-crater is the receptacle for all the house drainage; and in the same romantic region the Chinese laundryman attached to one of the hotels gets through his labours by throwing the clothes into a bubbling, frothy pool, and fishing them out when they have been tossed about enough. Eggs are often boiled in the Iceland geysers, and bacon is fried on the Hawaiian lava streams. In the Rotorua area of New Zealand the banks of the lake are so perforated with springs that every native hut has its own natural boiler, which is used as a kitchen. The Kuirua spring is strongly alkaline, and, on account of its saponaceous qualities, is utilised as a general wash-tub.

In Iceland to cook food in the geysers is a regular portion of the tourist programme. Tea is infused with water from the Great Geyser, and trout are boiled in the Blesi, or hot water pond, which suddenly ceased to erupt after the Skaptar-Jökull convulsion of 1784. They require to be immersed for about twenty minutes to be cooked to a turn. In the Yellowstone country a story is told of a fisherman, who having hooked a fine trout, merely turned on his heel and, without taking his captive off the line, plunged it into a pool of hot water, from which in a short time he drew it ready for his meal, reminding us of Lord Lovat, the Jacobite rebel, who, when luncheon time approached, betook himself to a fall on his estate famous for its leaping salmon, and placed a caldron of boiling water in such a position that a fish missing its spring would tumble into the pot. Neither story may be true, though there is nothing improbable in either.

M. Leclercq narrates how two Irishmen tried to cook their dinner at the Strokhr, in Iceland. A shoulder of mutton was wrapped in the body of a flannel shirt, and in each sleeve a plover was placed, and the load dropped into the geyser. After waiting for half an hour the shirt (with its contents) was hurled up high into the air, and landed on the brink of the basin. The mutton was "cooked as in England"—the French writer discreetly observes. But nothing was left of the birds except skin and bones; all colour had fled from the shirt, though the fabric remained uninjured. The hot water basins both in the Yellowstone country and in New Zealand are in great demand as bathing-places. Towards the close of the fourteenth century Nicolo Zeno saw Icelandic monks heating their rooms with the thermal springs in Julianehaab District, in South Greenland. To make a washing-tub of a crater is to utilise the forces of Nature to the utmost limits of prosaicism.

CHAPTER XI.

Geysers: their Cause: Unintermittent Hot Springs: Mud Volcanoes: Solfataras: etc.

The New Zealand Catastrophe as illustrative of the Cause of Geysers—The Theories advanced to account for the Intermittent Action—Cavern Theories—Tube Theories—The Difficulties in all of these Explanations—Some Peculiar Features in Geysers—Hot Springs generally—Source of their Heat—Mud Volcanoes—Solfataras, Fumaroles, Moffettes, and Discharges of Water by the Force of Compressed Air which simulate Geysers, etc.

The New Zealand catastrophe illustrates in a striking manner several of the most interesting features connected with geysers. Indeed, it may be asserted in general terms that the discharge by which the Pink and White Terraces were destroyed was really a geyser eruption on a large and complicated scale.

The cause of this sudden outburst is not very far to seek. New Zealand is a land of dying volcanic action. The volcanoes are getting into the solfatara stage, which, though geologically of much less importance than the lava period, can be sufficiently uncomfortable for those concerned. Even the old lion, toothless and decrepit, can, when roused, show something of its native strength. In the course of ages the endless boiling springs have dissolved all the materials beneath the crust, until it is in places quite cavernous. This was the opinion of Hochstetter in 1859. Some day, this geologist prophesied, "the whole of the mountain, up to the Te Kopiha fountain, being, as it seems, thoroughly decomposed by hot vapours, will cause a sudden catastrophe by falling in and covering the Rotoreka Plain with a flood of hot mud."

Mishaps of this character were not unknown in the history of New Zealand previous to the year 1886. In 1846 Mount Kakaremea, soddened by the constant steaming which it had received from the numerous hot springs in its vicinity, fell in an avalanche of scalding mud, overwhelming the Maori village of Te Rapa, and swallowing up its inhabitants. More than one hundred and twenty years ago the ground at Ohinemutu subsided, and a Maori stronghold was submerged in Lake Rotorua, which about that period had commenced boiling. "The posts and part of the carved wood of the old pah [stockaded post] still lie on the brink of the lake, no one venturing to touch what is esteemed a sacred ruin. It remains as a solemn warning to the settlers in the new city of Rotorua that what has once occurred may happen again. Meanwhile, the dead are laid to rest beneath the green turf beside these posts, which is constantly veiled by the steam of innumerable boiling springs." *

The eruption which created such havoc in June, 1886, was, therefore, due to the enormous accumulation of superheated steam from the water supplying the geysers and boiling springs beneath the cavernous crust, expanding and sending the sodden soil overhead into the air in the shape of an eruption of mud. This theory is in accordance with all the facts so far as yet ascertained, and is stated as follows by Sir James Hector, Director of the Geological Survey:—

"The Tarawera mountain, which was formerly a volcano, had been for ages heavily capped with obsidian, forming, as it were, an enormous glass dome hermetically sealing it. The pent forces have now blown this dome away. The tremendous explosion has shattered the tubes, or the piping of the Pink and White Terraces, which probably led thousands of feet into the superheated regions of the earth. This let down the whole of Lake Rotomahana,

* Miss Gordon-Cumming, on "The Eruption of Tarawera in 1886" (*Leisure Hour*, October, 1886).

and generated an inconceivable body of steam, which simply blew the entire valley and the adjoining river into the air. What was formerly the lake is now occupied by numerous mud volcanoes (Fig. 103). If this volcanic activity continues unabated, the district will, perhaps, afford in the future greater attractions to the tourist than even the vanished terraces, with all their matchless beauty."

In the meantime, in the district about Lake Okaro, range beyond range of smooth hills is strewn with finely-powdered dust which has been discharged directly from the regions of central fire; while the opposite direction, near Wairoa and Rotorua—a tract twenty miles by twelve—is for the most part smothered beneath the grey mud, believed to have been discharged from Lake Rotomahana. At present this mud has hardened like cement. But in time it will crumble down under the action of the weather, and, like most volcanic soils, will become more productive than the old earth which it has overlaid (p. 16)—especially as this was for the most part of a light pumice character, and almost valueless for agricultural or pastoral purposes. Altogether it has been estimated that more than 100 million tons of volcanic dust, pulverised scoriæ, or mud, have been spread very unequally over about one hundred square miles of country. These fell for eighteen hours in a ceaseless shower, which so effectually destroyed grass and fern and all the pasture down to the Bay of Plenty that, to again draw on the account from which so many of our facts have been culled, the very rats were starved, and their corpses lay scattered over the thirsty dust hills. "Even living birds were coated with mud, while for some days after the eruption the poor bewildered cattle roamed about this dreary wilderness mad with hunger and thirst, gnawing boughs of trees or decayed wood, bellowing pitifully, and with eyes bloodshot and nostrils choked with greasy slate-coloured mud, which lay, too, an inch thick all over their coats." Ships 130 miles from the scene of disturbance had their decks covered with dust from Tarawera.

Cause of Geysers.

It is clear from the data supplied in the preceding pages that steam is the propelling agent of the water which is shot out of geysers. Of this there is no doubt. But when we come to speculate as to the source whence this steam is derived, we are face to face with a difficulty almost identical with that which met us when the origin of the lava and the agent which ejected volcanic products were considered.

Cavern Theories.—Sir George Mackenzie's theory was for many years the most generally accepted one, and even yet forms the basis of several others formulated to overcome some of the difficulties which it presented. He inferred (Fig. 108) that the geyser pipe communicates at its lower extremity with some more or less deep-seated subterranean cavern, which gradually contracts, as shown in the above diagram. This cavern fills with water by means of rain or other surface water percolating through cracks in the rock. Then being heated by warmth conducted through the strata from the rocks below, or by steam percolating into it from cracks in the bottom, it will soon be partially filled with boiling contents. The steam generated will be sufficient to sustain the column of water in the tube. But if, by a sudden addition of heat, a quantity of steam is produced in starts, the expansive force will be so great that the water will overflow into the crater, at the top of the geyser cone. Then all the water in the cavern will

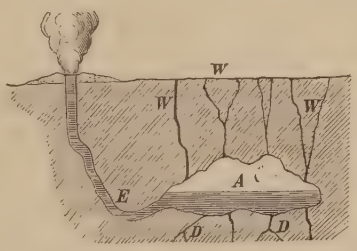


Fig. 108.—DIAGRAM ILLUSTRATING MACKENZIE'S THEORY OF GEYSER ERUPTIONS.

E, The geyser pipe, to which rain and surface water have access through the fissures w w w in the rock, in which the cavern A is hollowed; D D, Fissures through which steam percolates into the water from the under world.

be forced into the pipe, and the steam will rush through it with great violence, and an eruption will take place. Mackenzie regarded the shaking of the ground and the noises like the discharge of artillery which usually precede an eruption, as due to the evolution of steam in starts, due to this sudden accession of heat. Or if the water did not escape in the manner described, the steam "escaping round the neck of the cavern by pushing the water before it, would condense in the cooler water of the tube, and thus cause merely a rising and falling of the water within the basin above,"* as is seen in many geysers (pp. 192, 194).

Mackenzie's theory, however, while it takes cognisance of the action of the Little Geyser, does not explain the eruption of the Great Geyser, in Iceland, and does not account for the frequent and periodical production of the phenomena. But his merit is in having recognised the fact that sudden evolution of heat is the proximate cause of the eruption, and that to heat and the laws regulating its action we must in future confine our inquiries.

Bischof and Von Nidda formulated a theory almost exactly the same, and explained the eruptions of the Great Geyser and Strokhr by taking for granted that a smaller cavity fills quicker, and therefore empties itself more frequently, while a larger cavity fills slower, and empties itself seldomer, but with greater violence. Comstock also adopts the idea of the fountain-head of a geyser being a cavern containing water; but he tries to account for intermittent geyser action by supposing that after the tube leaves the first cavity it bends and forms a second one, from which the tube through which the discharge takes place rises to the surface. Baring-Gould also adopted Mackenzie's theory. "He took an iron tube," Dr. Peale tells us in his synopsis of geyser doctrines, "and bent it at an angle of 110°, keeping one arm half the length of the other. He filled the tube with water, and placed the short arm in the fire. For a moment the surface of the liquid remained quiet, and then the pipe began to quiver; a slight overflow took place, without any sign of ebullition, and then suddenly, with a throb, the whole column was forced into the air. With a tube, the long arm of which measured two feet, and the bore of which was three-eighths of an inch, he sent a jet to the height of eighteen feet. Steam is generated in the short arm, and presses down the water, causing an overflow, until the steam-bubble turns the angle, when it forces out the column in the long arm with incredible violence." However, though no doubt this apparatus is in some respects an approximation to the one employed by Nature, experiments with it do not altogether confirm this ingenious writer's conclusion that what happens is really analogous to a geyser eruption.

Tube Theory.—The theories noticed—and they are only a few out of many formulated—demand the admittance of a hypothetical subterranean cavity. But the explanation offered by Bunsen † claims to dispense with any such fountain-head of eruptive force. From observations made on the Great Geyser of Iceland, he concluded that its various eruptions were due to circumstances depending upon the different rates at which water boils at different depths. We know, for instance, that at the level of the sea it boils at 212° Fahr., and, the higher one ascends, the degree at which it boils is lower; while if we descend below the level of the sea—into the Jordan Valley, or into a mine, for example—the water will take proportionately long to attain the boiling-point. Hence, heights are conveniently measured by noting the exact temperature at which water boils at various elevations. These variations in the boiling-point are due to the influence of the pressure of the column of air overhead, this pressure being, of course, less at high elevations, and greater at lower ones. At the bottom of a deep pipe of water, it will necessarily follow that the pressure would be even greater than in the atmosphere, the entire superincumbent column of liquid keeping the water at the bottom of

* Barrett on "Geysers" in *Science for All*, Vol. I., pp. 225—227.

† He was assisted by Descloizeaux, and their conclusions have been largely confirmed by Müller of Freiburg, Wiedemann, Bryson, Douay, Tyndall, and Walker.

the tube from attaining the boiling-point, until it is far over 212°, while the water at a point considerably nearer the surface would be in a condition of steam from the heat derived from the water lower down. These well-known principles of physics—stated here in only the merest outline*—lie at the base of Bunsen's theory. In the Great Geyser of Iceland the geyser tube is a vertical pipe (Fig. 109). After each eruption the level of the water is about three to six feet down in the pipe (say about the line *a* in Fig. 109), and rises slowly from this level until it overflows. But it does not

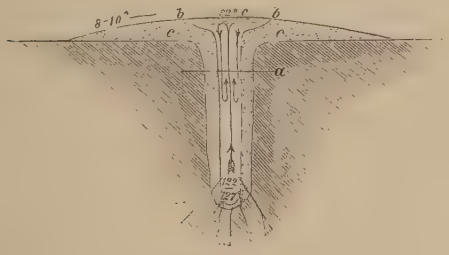


Fig. 109.—DIAGRAMMATIC SECTION OF THE GREAT GEYSER OF ICELAND. (*After Bunsen.*)

a, Level at which the water stands after an eruption ; *b b*, The geyser basin ; *c*, The deposits of silicious sinter. The temperatures are in Centigrade degrees.† 82° C. = 179·60 Fahr.; 122° C. = 251·60 Fahr.; 127° C. = 260·60 Fahr.

all run away. Part of it is cooled at the edge of the basin (Fig. 109, *b b*), and returns along the side of the pipe to the bottom, where it is again heated, and lifted up again by the current which the ascending steam forms in the middle. If we throw bits of paper into the water after an eruption, we are able to satisfy ourselves regarding these currents of the water

* The reader may again be referred to Professor Barrett's admirable paper for a full exposition of these doctrines, though probably Bunsen's theory is accepted there with too few reservations, recent observations throwing some doubt on the conclusion that it is applicable to every geyser.

† In the text of this work the temperatures, when the contrary is not stated, are all given in degrees Fahrenheit. But the English-speaking peoples and the Russians are almost alone in using this scale, the Centigrade (or Celsius) or Reaumur being used by other nations. In this country also scientific men commonly employ the Centigrade scale, though, as happens with the decimal currency weights and measures, the general public do not as yet seem ripe for accepting anything so simple.

on the surface (p. 194). Observation has also shown not only that the temperature of the column of water decreases from below upwards (that is, it is always hotter lower down than farther up), but also that between one eruption and the next one the temperature is constantly rising at every point, so that while, for example, at a depth of from nineteen to twenty-two feet the temperature after an eruption is 194°, an hour later it is close on 196° ; and, lastly, that during the whole time between the two eruptions the temperature of any point of the water column is lower than the boiling-point corresponding to the pressure on this point.

In the middle of the geyser pipe the temperature comes nearest to the boiling-point. At the bottom the temperature is higher than the ordinary boiling-point of water, but the water is prevented from boiling by the pressure of the water column above it. When, through the constant rise of the temperature caused by the overheated water steaming upwards, the boiling-point corresponding to the height of the pressure in the central region is reached, a layer of water will immediately transform itself into steam, and cause an upheaval of the surface. However, the next layer above it will also be affected, and transformed into steam, and so force up a larger or smaller amount of the lower part of the water column, until the upper portion of the column is projected with great force into the air.

Here it becomes cooled, and falling back into the basin temporarily checks the formation of steam, until enough water of a very high temperature has risen to again raise the superincumbent portion to the boiling-point, when the eruption begins *de novo*. This lasts just as long as the conditions described are in force. When the cooled water, falling again into the basin, restores the equilibrium down below, and the hot water from the bottom of the tube has not power to heat the superincumbent layer sufficiently to form the ejecting steam, the eruption ceases. During an eruption a great deal of water falls outside the crater. This is the reason why the level

of the water is, after an eruption, several feet lower than before it began. The length of the period of quiescence is, of course, dependent upon the quantity and the temperature of the water from below, and also on the depth and width of the pipe. It must also be to some extent influenced by the weather, whether it is wet or dry, since the water, which is the chief factor in a geyser display, must necessarily be derived from the atmosphere, and find its way into the tube either from above or from below as in Figs. 108, 109, or possibly from both quarters. On this account the interval between two eruptions differs not only in different geysers, but also in the same fountains at different times. Most of our data regarding the conditions which prevail in the tube are necessarily inferential. Still, it is tolerably certain that the lower strata of water are not disturbed by an eruption. Bunsen hung stones by strings to the pipe, and found that only those in the higher levels were ejected by the rush of water, while those at or near the bottom were undisturbed, and a thermometer sunk at the bottom of the geyser remained quiet and unbroken during an eruption.

Difficulties in Geyser Theories.—None of these theories, however, explain quite satisfactorily all the phenomena of every class of geyser, though, possibly, Bunsen's is on the whole the one which is most generally accepted. The variations noticed in different geysers may depend on variations of the form of the tube, or subterranean water passages, even should we be content to dismiss the idea of subterranean cavities. Geysers close together have evidently no connection with each other, otherwise the level of the water in their pipes and basins would not be different; while if they were impelled by the same motive power it is certain that they would be more sympathetic in their action, instead of being capricious in the extreme, two geysers within a few feet of each other having eruptions of widely different duration and interval. Indeed, it is quite common to see a geyser in the Yellowstone country in violent eruption, while the caldrons of others on the same or on different levels, but hard by, are perfectly placid. This proves to demonstration that these geysers at least do not all proceed from the same reservoir, though, at the same time, the facts mentioned do not quite preclude the acceptance of the old idea of a subterranean reservoir being the fountain-head of a geyser, as originally suggested by Mackenzie. Indeed, the phenomena presented by some geysers—especially those in the Yellowstone country—are better explained by some modification of the "cavern theory" than by that of Bunsen, which is framed solely upon observations made on the Great Geyser of Iceland.

The difference between the two theories lies in this. Suppose a tube filled with water, and heated rapidly at the bottom; the water will, when the boiling-point is reached, be violently expelled from the top. This, in part at least, is a simple illustration of Bunsen's theory. But if the water is put in a tea-kettle and boiled into steam, then either the lid will be blown off, or the steam, with or without water, will escape through the spout. This is an exemplification of the theory which presupposes a subterranean cavern, with an opening to the surface. But the gulf between the two theories is not so broad as might be supposed from this crude statement of their elements. Both admit steam to be the agent which expels the geyser column, and both presuppose that at a certain depth in the earth the rocks must be so warm that the heat imparted by them can boil the water—be it in cavern or in closed tube—so as to generate the requisite amount of steam demanded for the expulsion of the water. Or, if not, then the water must be heated by steam, which penetrates the tube or the cavern from quarters where there is heat enough to generate this vaporous form of water. Where the heat comes from is immaterial; the main point is, that it must be there. In the Great Geyser, it is believed, from some observations made, that it does actually enter at the side at a depth of about forty-five feet in the tube; and in the Strokhr there are openings on opposite sides of its tube through which, when the tube is empty, water and steam can be seen

Fig. 110.—THE GRAND GEYSER OF THE YELLOWSTONE PARK.

pouring. This steam must come from some other region, and in all likelihood is evolved in caverns. That such must exist is rendered probable from the way in which geysers are first formed, namely, by violent outbursts of steam and water, conditions which render "irregular cavities and passages" more "likely to be formed than regular tubes, which are a subsequent growth from the deposition of silica deposits around the opening through which the column of steam and water is discharged by the geyser."

Dr. Peale, who suggests this very reasonable explanation, is therefore inclined to regard Bunsen's theory as a mere modification and expansion of Mackenzie's, and at best explanatory of only a part of geyser phenomena, since it seems to require subterranean cavities in which the water must be heated. Whether these are caverns, enlargement of tubes, or tributary channels, is of the smallest importance, except in so far as the interval between two eruptions might be affected by the form of the reservoir holding the water.

These variations may be affected by the size or shape of the geyser tubes, and many other circumstances at the nature of which we can only guess. In Iceland the geysers are much simpler than those in the Yellowstone country and in New Zealand. In the Yellowstone Park there are, according to Dr. Peale, four classes of spouting springs, if they are grouped according to the characteristics of their eruptions, but without regard to the length of their intervals. (1), There are those in which, like Old Faithful and the Beehive, the action is confined to one eruption, and is not followed by a marked steam period. (2), Those, like the Castle, in which the eruption consists of a single water period, but followed by a marked steam period of considerable length. (3), Those which have several water eruptions, separated by an interval of several minutes or hours, while the regular interval is from a day to several weeks; the Grand (Fig. 110) and the Giantess are examples of this kind. (4), The Giant and the Union are types of geysers in which there are water periods, as in the third class: but these are followed by a marked steam period. Various irregularities in the shape of the geyser tube may be regarded as the principal factor in causing the peculiarities described, though the methods in which the heat is supplied to the tube, or to the cavern—since both may exist in various combinations—is certain to have an even greater influence.

The effect of the atmosphere on geysers has long been noticed (pp. 206, 207). One of the New Zealand spouting springs was known to the Maoris as "Tapui," the wind-pointer, from the fact that it only discharged when there were north and east winds. Again, the springs at Whakarewarewa are most active when the wind is in the south-west and west; while that behind Te Tarata used to recede from its basin when the south wind blew. Others were quiescent during certain months in the year, facts which are interesting when we compare them with the ideas of the people of Stromboli regarding the eruptions being most frequent during certain directions of the wind (p. 144), or the better-ascertained fact that the paroxysms are most violent during the winter.* How the weather influences these eruptions we cannot say. No doubt, however, the supply of water, which must, of course, proceed from the surface, has its effect on the greater or smaller amount of discharge, or upon the greater or less frequency of the eruptions. The source of the heat which boils the water into steam, or warms hot springs generally need not be discussed after what has already been said regarding the origin of volcanic action (pp. 179—182). Both must be identical in origin.

A geyser is, in truth, only another form of volcano—one which discharges water instead of ashes and lava. Both depend on water for their active phenomena; in both there is a periodicity, though the volcano requires as many years as the geyser demands hours for the renewal of its expended force; and though the volcano may live for more centuries than the geyser years, both alike have

* Mair: *Transactions of the New Zealand Institute*, Vol. IX., pp. 22—29.

their limit of duration. They gradually decline, and then, after a feeble old age, become extinct, the geyser in its various forms being mainly found in regions where volcanic action is dead or dormant, so that the water-volcano may — like the gas-volcano — be regarded as the expiring effort of the subterranean giant.

Unintermittent Hot Springs.—A true geyser—that is, one dependent on steam for its motive power—must necessarily discharge hot water. But the finest features of the geyser districts we have described are not necessarily due to intermittent springs, but to the silicious, or calcareous, deposits from those which flow out of the ground more or less unintermittently, though the origin of the two is unquestionably the same. They must both derive their heat from some deep subterranean source, though rocks have such different conducting power that it is idle, from a consideration of the rate at which temperature increases as we descend into the earth, to calculate the depth at which the temperature of any particular spring must have been attained. It is enough for us to know that when we see—as we frequently do—two springs flowing side by side, the one cold and the other warm, that the first must come from a considerable depth, while the other is more of surface origin. Nor, though volcanic districts are most markedly distinguished by the presence of hot springs, does it necessarily follow that they are confined to such regions. Those of Bath and Buxton, in England, for example, are in a part of the world far removed from any active volcanoes. In their course through the earth they dissolve out of the rocks the various soluble materials with which they come in contact. The chief substances thus held in solution when they come to the surface are silica and carbonate of lime. To the deposition of the silica, when the water evaporated, were due the famous Pink and White Terraces; but the almost equally remarkable terraces, at the Mammoth Hot Springs (Fig. 101), are composed of calcareous material. The same kind of terrace may be seen near the ruins of Hierapolis, in Asia Minor, known to the Turks as Panbouk Kalessi, or the "Cotton Castle." Mr. Abram describes this terrace when viewed from the opposite mountains, some twenty miles away, as looking like a breastplate of silver on a giant's body. The springs, laden with limy matter, in descending from a great elevation on the Missougis Range, have left their solid matter behind in dazzling white cataracts, which seem like frozen waterfalls running into natural basins of beautiful and varied geometrical shapes, all stalagmite-covered petrifactions of fantastic forms. On the high plateau from whence these springs descend are the ruins of a temple, once appropriately dedicated to Pluto. The holy hot bath which stood in the temple courtyard, surrounded by a colonnade, is still in fine preservation, and beneath its deep clear blue waters can be seen many a fluted column and finely-carved cornice. Sulphurous gas is continually bubbling up from the bottom of the bath. The chief source of the springs is a cave—the ancient Plutoneum—from which issues a gas described as "fatal to animal life." This is most probably carbonic acid. But not far off is a ruined fountain and cistern, near to a cave of sweet water, which supplied the whole town with that necessary of life.

Other materials beside silica and lime enter into these hot springs; indeed, almost any soluble substance may be taken up. In Iceland, for example, there is much copper, and in New Zealand common salt, dissolved in the geyser and other hot springs. The amount of solid matter deposited from them is shown by the vast heaps of silicious and calcareous matter which have been piled around the crater of geysers and along the course of hot springs. The springs of Huancavelica, in Peru, have deposited so much stony material that, like travertine (p. 66), it is quarried for building purposes. The hot springs of Carlsbad have deposited pisolite (Strudelstein) in masses sufficiently large to fill up the whole bottom of the valley, and upon these deposits the town itself is mainly built; and it has been calculated that if the deposits from the hot springs at Bath were

collected, it would be found that in 2,000 years they would form a solid cone equal in height to Monte Nuovo, in Italy;* and Strabo, speaking of the springs of Hierapolis, declares that when the people of the city wanted a wall, they simply conducted the lime-laden waters into ditches: then the deposit formed a solid dyke! These examples are altogether taken from calcareous deposits, tufa, or travertine, owing to the greater ease with which it is devolved out and laid down, accumulating much faster than silica sinter. Under favourable circumstances about one-sixteenth of an inch of calcareous matter is deposited by the Mammoth Hot Springs rates, the rate of deposition may depend on a variety of circumstances. Much less, is it safe to reckon the age of any deposit from observations made on another only a short distance away. Springs laden with calcareous matter part with it simply by cooling and losing carbonic acid, while the silicious waters, so far as we at present know, deposit the silica or geyserite on evaporation, "as it flows from the springs or falls from the geyser," though where there is a superfluity of silica some may be precipitated when the water cools.

Birth and Death of Geysers.—Between a geyser and an ordinary hot spring—in other words, between an intermittent and a non-

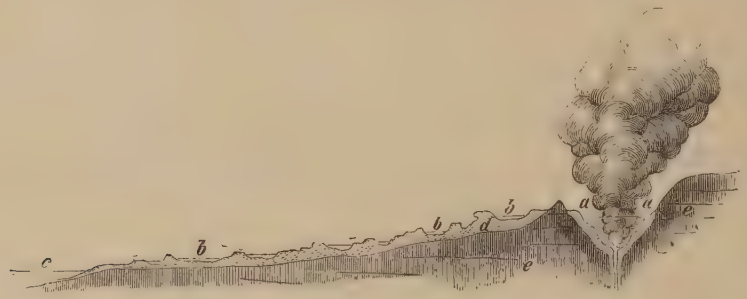


Fig. 111.—SECTION THROUGH THE CRATER AND THE SINTER TERRACE OF TE TARATA (THE WHITE TERRACE), OF NEW ZEALAND, BEFORE ITS DESTRUCTION IN 1886.

a a, The crater of the geyser; *b b b*, The basins on the terrace; *c*, The surface of Rotomahana; *d*, the accumulations of silicious sinter or geyserite; *e e*, Underlying rock of Rhyolite (liparite, or quartz-trachyte).

in four days, while it takes fully twenty-four hours for the Great Geyser in Iceland to leave behind it a layer equal to the thickness of a very thin sheet of paper, and so slowly was the silica deposited by the springs forming the Pink Terrace, in New Zealand, that the names of tourists, written in pencil thirty years before, could easily be read through the thin film which had in the interval covered the pencil marks. On the other hand, whatever lay upon the Te Tarata terrace became encrusted in a short time (Fig. 111). It is, therefore, impossible to calculate with much approach to accuracy the age of any geyser or hot spring deposit, from the thickness of the material which it lays down; for as the material is deposited only when the water evapo-

* Judd: "Volcanoes," pp. 184, 219.

intermittent one—the difference is one of degree rather than of kind. Between the two there is every gradation, and the one may turn into the other, or *vice versâ*. If Bunsen's theory is well founded, a hot spring forming a tube will in time become a geyser, and by still further raising this tube, make the pressure of the contained column of water so great that it will cease to work. A spring, let us suppose, flows hot out of the ground, and then, when its waters dry up, leaves a deposit of silica or tufa behind. This in time forms an embankment around the opening of the spring, which by-and-by grows into a basin from which a tube leads the water to the surface. "But if the tube grows higher and higher, and the column of water within deeper, and the pressure below greater, a more exalted

temperature is necessary to reach the boiling-point, and hence longer and more uncertain periods should intervene between each eruption. At length, if the previous accretion be continued, we should expect to find an eruption at rare intervals; and ultimately the great depth of the column of water would create so enormous a pressure, that the temperature of the boiling-point would never be reached by the source of heat below, and the geyser would then cease to erupt at all."

This concise theoretical statement of Professor Barrett is confirmed by actual facts. In the earliest accounts of Iceland—which extend back for 1,000 years, and are so circumstantial on less important matters that it is almost certain the historians would not omit to mention phenomena so remarkable as spouting springs—there is no mention whatever of the geysers. But as Saxo Grammaticus notices the Great Geyser in his history of Denmark, written towards the close of the thirteenth century, it must have been known before that date. Possibly, the volcanic eruption of 1294 caused the disappearance of many thermal springs, and produced those now existing. Two hundred and fifty years ago, the Geyser spouted regularly once in twenty-four hours. In 1770 its eruption had increased to eleven times a day; by 1814 it erupted only once every six hours; in 1872, once or twice a week; and nowadays travellers will sometimes wait a week, and even a fortnight, before the waning geyser can recover sufficient force to play.

The height of the column discharged seems also to have decreased in the same ratio, thus confirming the theory that as the tube grows higher by accretions round its mouth, and the column of water within deeper, and the pressure below greater, a higher temperature is necessary to reach the boiling-point, Hence, also, "longer and more uncertain periods should intervene between each eruption," until, if this process of deepening goes on, the geyser will in time "cease to erupt at all." Indeed, this rise and decline of geysers are a common observation in any geyser country. In Iceland we have seen that the Strokhr was before 1789 an inconsiderable spring, and that the "Roaring Geyser" of that date has now become a quiet spring (p. 195), and in the neighbourhood of still active fountains may frequently be seen mounds of silica, on the top of which are quiet pools or "laugs" of great depth, which bear every appearance of having been extinct geysers. The pipe still communicates with the subterranean world, but no motion is ever seen in the crater; while in other places a further stage of decadence is displayed in craters now altogether dry, and the pipe, which at one time was the outlet for spouting columns, altogether choked up with stones and other rubbish. In the Yellowstone country geysers have come into life since it was first explored (p. 196).

Thus a geyser begins by being a hot spring; by-and-by it becomes a geyser; then, as it destroys its power by its own energy in depositing silica, or whatever other material its waters may hold in solution, it sinks into the condition of a "laug," which for a while steams occasionally, until in time even this last remnant of former greatness deserts it, and the geyser can be traced only by its round shaft and sepulchral mound.* The converse of this destruction of geyser action by relieving the superincumbent pressure to some extent was exemplified in an experiment by Mr. Baring-Gould, which is worthy of mention. "We raised," he tells us, "the depth of the well south of the blue ponds twenty feet, by turning the stream from these ponds into it, and completely altered its character, converting it from a well of furiously boiling water to a pool steaming tranquilly. Not satisfied with this experiment, we tried another, and dug into a small puddle of hot mud. It was at once converted into a bubbling pool of five jets."

* Forbes: "Iceland: Its Volcanoes, Geysers, and Glaciers" (1860); Burton: "Ultima Thule" (1875); Pajkull: "A Summer in Iceland" (1868); Coles: "Summer Travelling in Iceland" (1882); etc. A full bibliography of geysers and other thermal springs is given by Peale.

Mud Volcanoes.

These must be carefully distinguished from true volcanoes, which at the beginning of their outbreak discharge copious floods of mud (p. 138). In reality, the phenomena which form the subject of this paragraph are not volcanoes at all, but are more nearly akin to, if not in some respects identical with, those of geysers. Even then, one and perhaps the most common form of "mud volcanoes," so called, are actually only boiling mud wells, caused by the steam continually ascending through the porous soil, so soddening it at places that the crust falls in and the spot becomes a pit or pond where the resultant mud is continually seething. This form of "mud volcano" is common in most volcanic or geyser districts. In New Zealand, we have seen, it exists almost everywhere; and both in Iceland and the Yellowstone, among other localities, excellent examples of these mud holes may be found both in an active and an extinct condition. The holes are only vents in what is probably a great caldron of mud below, covered with a thin crust, through which, at spots like these, the imprisoned steam has burst. The consistence of this mud varies from that of thick treacle to a liquid which is simply ink-black water. "The thundering and throbbing of these boilers," a visitor to those of Iceland has remarked, "the thud-thud of the hot waves chafing their barriers, the hissing and spluttering of the smaller fumaroles, 'the plop-plop' of the little mud pools, and above all the scream of a steam-whistle at the edge of a blue slime pool, produce an effect truly horrible. In some of the caldrons the mud is boiling furiously, sending sundry squirts into the air; in others, balls of black filth rise and explode into scalding sprinklings; in one a foaming curd forms on the fluid, and the whole mass palpitates gently for a moment, then throbs violently, surges up the well, and bursts into a frenzied, roaring pool of slush, squirting, reeling, whirling in paroxysms against the crumbling sides, which melt like butter before its fury. One or two of the springs have heaped themselves mounds around their orifices; others gape in the surface without warning; and the steam is so dense and the sulphurous fumes so suffocating that one becomes bewildered and can hardly pick one's way among them."* This graphic description applies with equal aptitude to the mud springs of similar origin elsewhere. In the Yellowstone country the mud is in some pits as stiff as mortar, in others it is like paint, the thickness or thinness of their contents being greatly influenced by the wetness or dryness of the season. They are also of all colours—red, white, lavender, grey, or blue—and nearly all give off the evil-smelling gas known as sulphuretted hydrogen. Sometimes in pools, when the mud is more than usually stiff and the steam meets with unusual resistance, the liquid mud oozing up from below through the newly-formed vents forms regular cones sometimes a foot or more in height, and occasionally with crater-like openings on their summits. Such cones are often seen in New Zealand and the Yellowstone Park, and in Southern California there are from three to fifteen such cones in a space 500 by 350 yards —some sharp, some dome-shaped. Steam rushes constantly from many, and is intermittent in some. One throws a stream of water from fifteen to thirty feet into the air.† Again, in North-Western Nevada, near Granite Creek Station, there are mud springs—as they ought properly to be called, unless, indeed, mud wells would not be more appropriate—the contents of which are thrown up and violently agitated at regular intervals, accompanied by puffs of steam, which show a close approximation to geyser action. Several of these springs have built up cones of hardened mud, all with one exception closed at the top. In this one the aperture emits sulphuretted hydrogen, and occasionally throws out mud and water in all directions.‡ In Sumatra there is something even more pronounced, though of exactly the same character (p. 202). The "Mud Geyser" of Hayden's Valley, in the Yellowstone Park,

* Baring-Gould: "Iceland," p. 141.

† Veatch: *Proceedings of the Californian Academy of Sciences*, 1857, p. 104.

‡ Hague and Emmons: "United States Geological Survey of the Fortieth Parallel," Vol. II., p. 799.

is simply an ordinary geyser, into the waters of which mud enters owing to the mode in which they break through the soil. There is thus every gradation between the clear and the muddy well, just as there is between the unintermittent and the intermittent springs. After a time a mud hole may get choked by the "caving in" of its banks. Then the steam or the hot spray, which works the earth up into mud, will seek an easier outlet, and the once seething mud hole will remain a dead pit among its still active kindred.

There is, however, another form of mud volcano common in Sicily, Kertch, the Baku district of the Caspian, and elsewhere, which goes by the name of Salses or air volcanoes, and, in Sicily, of Macalubas, which consist of conical hillocks of mud, chalk, gypsum, and various saline ingredients, including common salt (hence the name *Salses*), which are formed of materials continually ejected from orifices in the soil by the agency of various gases, such as carbonic acid, sulphuretted hydrogen, and nitrogen, with petroleum vapours, as in the cases already cited from the Baku district (pp. 142, 143). The source of these salses is not quite the same as in those just described, for the mud being generally cold we are not permitted to infer that steam has had much to do with such eruptions. In the Taman and Kertch districts large stones, different from those forming the surface strata of the immediate neighbourhood, are also sometimes ejected,* and as flames in some instances issue from the vent it is reasonable to suppose that the source of disturbance is often deep-seated. The flames are, however, only gases, or petroleum vapours ignited, and these owe their origin to the same distilling processes which have originated the gases accompanying them. Sometimes—as in the case described—the forces causing the formation of the cones display unusual violence. As a rule, however, the hillocks (Fig. 103) vary from a foot or two to between six and seven hundred feet, and even higher, though these comparatively lofty elevations are much rarer than the lower ones. If washed away by rain, the soil is spread out on the neighbouring country. But by-and-by the tiny eruptions begin afresh, and the hillocks form either there or in some other spot in the vicinity of the old vents. When naphtha or petroleum enters into the composition of such mud volcanoes they are known as Salinellas. The macalubas of Sicily —so called from Macaluba, near Girgenti, where numbers of them are found—throw out mud and bituminous matter. Dr. Daubeny attributed their activity to the combustion of beds of sulphur, in that quarter associated with the blue clays, amid which these mud eruptions take place. The gases given off consist of carbonic acid and carburetted hydrogen, which, when the macaluba is at rest, bubble up through the mud and bitumen, which is usually at a temperature of from 68° to 72°. The Salinellas of Paterno, at the foot of Etna, which have a temperature of from 55½° to 98½°, and the mud volcanoes of the shores of the Caspian, which show a temperature of from 89° to 98½°, are of much the same nature. We see an apt specimen of these salses in the Arsena of the Caspian region—a hill 984 feet high, with an elliptical crater less than two-thirds the size of that of Vesuvius, the entire cone having been formed by the eruptions of mud on a larger scale than usual.

A mud volcano is thus the earliest stage of a volcano. It is too early to speculate as to their final form. Some may become extinct; others will, however, undoubtedly develop, and not a few, especially of the mud wells, may in time take the form of a true volcano vomiting forth ashes and lava.

Solfataras, Fumaroles, Moffettes, etc.

Solfataras.—When a volcano is on the wane, only steam, various gases, and other emanations, are given off. It is then described as being in the solfatara stage—*the* Solfatara being a half-extinct volcano near Naples; from which since the only recorded eruption from it attended with a lava discharge—namely, that of 1198—only steam and sulphurous gases have been emitted. The volcano on the Island of Vulcano is also in this

* Murchison: "Geology of Russia in Europe and the Ural Mountains," Vol. I., p. 576.

condition of decrepitude. The "Soffioni" of the old volcanic tracts of Italy may also be regarded as dying volcanic vents, which have gradually passed into the solfatara phase. The gases which they give off are carbonic acid, sulphuretted hydrogen, hydrochloric acid, etc., which form combinations with each other or with the substances they come into contact with on the surface. In Tuscany the "Soffioni" discharge into lagoons, where they form a precipitate of boracic acid, sulphur, gypsum, and other substances. A good specimen of the solfatara is afforded by the crater of Tangkuban Prahu, in Java. This is also an example of a twin crater; the Western, or Kawa Upas, (the Poison Crater), is filled with mud, sulphurous materials, etc., while the Eastern, known as Kawa Ratu, or the King's crater (see Plate), discharges steam and sometimes mud. The last eruption was in 1846, when there were emitted large quantities of hot water, mud, stones, and sand, and the surrounding forest became charred by the outflow. Since then only steam and gas have been discharged, so that the volcano may be regarded as having now reached the solfatara stage on the road to decay.

Fumaroles and Moffettes.—A vapour vent, not necessarily a crater from which fumes are emitted, is known as a "fumarole."* They are often seen in lava streams in the process of cooling (p. 147). A "moffette," again, marks a still more advanced stage in the decrepitude of a volcano. The name is derived from the "Moffette," a pool not far from Benevento, in Southern Italy, which is always overhung by a dense layer of carbonic acid. It is identified with the Lake of Amsanatus described by Virgil (Æn. VII., 560—568), on the shores of which was once a temple to Mephitis, hence the modern name. In summer the pool is often a mere bed of sun-dried sulphurous mud, out of the cracks in which the evil vapours rise in such quantity that birds die when they fly across it, though when the deadly effect of carbonic acid on animal life is known this circumstance is not at all "una curiosa maladetta," as an early Italian writer characterises it. However, though sulphurous fumes mingle with the carbonic acid arising from Le Moffette, the vents which take their name from it emit only the latter gas, either singly or mingled with water, generally in a cold state. Some of these humble representatives of volcanoes we have already noticed while discussing the origin of the vapours which accompany or follow an eruption (pp. 128, 140—143).

Moffettes are especially found in districts subjected to volcanic disturbances, or which have at a comparatively late date been the scene of eruptions—such as the Eifel, Auvergne (Watterau), and Java. In Southern Italy they are very frequent. The Grotta del Cane—the Dog's Cave—near Naples, is an example of a cavity in which carbonic acid (a heavy vapour) accumulates in such quantity that a dog if immersed in it for a few seconds is rendered insensible. It is affirmed that this grotto was used as a place of execution for Turkish captives, who, when shut up in the atmosphere of this "breathing-place of Pluto," as Pliny called it, soon met with that easy death which is so often the fate of those who fall asleep in a closed room heated with charcoal in an open brazier. The grotto is to the south-east of the Lago d'Agnano, an ancient crater lake, two miles in circumference, but now entirely drained of its former contents. All this region is cavernous. Near the Solfatara, for example, a large stone thrown violently on the hollow ground makes a report like distant artillery, and it is affirmed that at some points water can be heard boiling beneath the surface.† Around the Lake of Avernus were of old erected temples to appease the infernal gods, from whose abodes the pestilential vapours oozed through the soil. Here Ulysses is fabled to have descended to the Shades, and it was believed that no bird could fly across its poisoned waters and live, a belief not improbably founded on fact, though no longer the case, for Augustus cut a canal, first to admit the waters of the Lucrine Lake, and then those of the sea, into the stagnant Avernus, so that he might form the Portus Julius.

* Italian, literally a smoker: plural *fumaroli*, though generally Anglicised into fumaroles, just as *solfatare* are into solfataras.

† Hare: "Southern Italy and Sicily" (1883), pp. 156–158, 163, 164.

THE NORTH CAPE OF HELIGOLAND SEEN FROM THE WESTERN SIDE

(AFTER A WATER COLOUR PAINTING BY J. HOFMANN.)

The amount of carbonic acid which is discharged by these moffettes must be enormous. 196,370 and 261,705 pounds of the gas, mingled with some oxygen and nitrogen. The amount

Fig. 112.—JESUITS' CHURCH, AREQUIPA, PERU, AFTER THE EARTHQUAKE OF 1868.

One "gas spring" at Burgbrohl, in the Eifel (p. 128), has, according to an estimate by Bischoff, produced, in the course of a single year between 1,546,505 and 2,062,250 cubic feet, or between discharged by some springs in the neighbourhood of Marienbad, where there is an old volcanic crater, is, according to Heidler, 3,600 cubic feet daily, or 1·3 million of cubic feet in

a year. This serves to impregnate the baths of Marienquelle, which are so rich in carbonic acid, that over this and the numerous other springs of the same character, the atmosphere is for the height of two feet so dense that a burning candle lowered to the surface of the water is immediately extinguished. This carbonic acid is, however, not derived from the decomposition of organic remains, but from the action of acidulated water on the underlying limestones, etc. At Burgbrohl, it may be added, the springs charged with carbonic acid deposit huge masses of calcareous tufa, like that which, we have seen, has accumulated from the hot springs of Carlsbad (p. 55). In this the amount of solid matter is so great that the openings in the "Sprudelschale" or hard rock, through which the imprisoned waters of the vast subterranean reservoir, or "Sprudelkessel" escape, have to be cleared and enlarged every three months. If the water and gas are prevented from emerging at any one particular spot, they will either burst through the obstruction or force a new passage for themselves, to the imminent risk of the buildings overhead being subjected to a geyser-like eruption. At the time of the Lisbon earthquake the "Sprudel" ceased to flow for three days. This shows, as we shall have occasion to demonstrate more fully at a later stage (pp. 250, 251), the influence of earth tremors on the drainage. During the same catastrophe at Lisbon the springs of Teplitz became muddy, then disappeared, and, finally, flowed more copiously than before. Those of Clifton, in England, and of Baden near Vienna, also became turbid, and at Luchon, in France, the "Source de la Reine," a merely tepid spring, suddenly attained the temperature of 122°, which it has retained. The thermal springs of St. Eufemia, in Terra di Amato, were unknown until the earthquake of 1638, and after the Calabrian one of 1783 they became hotter and more copious. After the Lisbon earthquake, all the Baden springs became richer in carbonic acid than before, and the one supplying the "Angel's Bath" appeared at that date. In 1770 hot springs broke out in San Domingo after an earthquake, but soon ceased to flow; while, on the other hand, the hot springs of Bagnères de Bigorre became cold after the shocks of 1660.

Finally, it may be added that springs containing a large amount of gas may simulate geysers. Dr. Peale, for example, mentions that the Kane Geyser Well in Pennsylvania spouts regularly, the eruption being due to gas. An artesian well at Rank Herlany, in Hungary (1,457 feet deep, and of a temperature as high as 75°), spouts to the height of 100 feet at regular intervals, owing to the fact that it contains more carbonic acid than water in its volume. The spouting of petroleum wells is often due to a similar cause.

It is thus clear that between a volcano vomiting forth lava and fiery ashes and an effervescing ("soda") spring, the water of which forms a pleasant drink or an agreeable bath, there are all manner of gradations. They belong, in brief, to the same category of subterranean phenomena; though probably between the two extremes it is not always possible to find the exact links. Not unlikely the deeper sources of the more violent and the shallower origin of the milder of these various phenomena may account for much which is otherwise difficult to understand.

From the volcano to the geyser the leap is not great, and, as we have seen, the hot spring may turn into a geyser, and the geyser return to the unintermittent hot spring stage. Again, between the boiling and the moderately hot spring it is not difficult to find gradations—while the effervescing and the still ones are in like manner separated by no violent breaks. Indeed, from those which have formed the theme of the last chapter to those which will come to be considered under the subject of springs and rivers, the passage is very easy. Before, however, entering upon the subject of the agents that wear down the surface which the volcano and the "secular rise" have elevated, it is necessary to consider the character of earthquakes; but as much of what has been already said has led up to this subject we shall not require to discuss these tremblings of the unstable land at such length as would otherwise have been demanded of us.

CHAPTER XII.

Earthquakes: Their Characteristics, and Causes.

General Character of Earth Tremors—Relation between Volcanoes and Earthquakes—Their Origin—Mallet's and other Theories—Centre of Impulse—Seismic Vertical—Coseismal Lines—Phenomena Attending—Effects of Earthquakes on the Crust of the Globe—Seismic Waves—Distribution of Earthquakes—Seismic Bands—Intensity of Shock—Scale for expressing Relative Destructiveness—Constant Tremulousness of the Earth—Observations of Bartelli and other Italian Geologists—And of the Brothers Darwin in England—Weight of Sea Pressure—Earth Pulsations.

No matter what theory is advocated as to the cause of volcanic disturbances, all agree in regarding these violent outbursts as due to something of the nature of an explosion in or below the solid crust of the earth, the only difference of opinion being as to what the explosion, or commotion, is caused by. It must, however, sometimes happen that these subterranean disturbances do not result in a volcanic eruption. Either they are not severe enough to burst through the superincumbent strata, or they are of such a character that the force, instead of acting in an upward direction, is propagated through the crust in a lateral direction by a series of waves. In this case, an earthquake is the result.

Connection with Volcanoes.—That earthquakes are closely allied to volcanoes is proved by the following facts:—(1), that volcanic districts are also those frequently affected by earthquakes; (2), that a volcanic outburst is generally preceded by a greater or less number of earth tremors; and (3) that a volcanic outburst is often the signal for earth shakings in another or the same region to suddenly cease. The crater seems to act like a safety-valve for the labouring earth. For instance, when the volcano of St. Vincent, which had been dormant for the better part of a century, burst into renewed action, the earthquakes in South America, which for many months previously had been more than usually lively, ceased. In California, also, it is often remarked that earthquakes are rare while the Hawaiian volcanoes are at work. At the same time, though there is thus a close connection between the two sets of phenomena there are plenty of earthquakes in quarters of the world where volcanoes are unknown. Spain and Portugal, for example, have been the scene of some of the most tremendous of modern earthquakes. Yet there are no active craters in the Peninsula. Great Britain is also a region of mild, though steady "seismic"* action; there have been within the period over which history extends several tolerably severe shocks in these islands, though, with few exceptions, most of them have done no more damage than causing a sensible tremor, a breakage of crockery, or, at worst—like that of Essex in 1884—a wreckage of church spires and old houses. Yet, though the Britain of the past was a land of oft-repeated volcanic action, at present the nearest active volcanoes are those of Iceland. Indeed, the instruments set up in the tower of Comrie Church, in Perthshire, show that the earth is seldom absolutely still, faint tremors being of continual occurrence, though the bulk of them are so mild as to be unperceived by the human senses.

Frequency.—At some time or other there is—we may take it—an earthquake shock in progress almost everywhere; but in addition to the thousands recorded, tens of thousands more have been experienced, though not considered worthy of their incidents being preserved in writing or in popular tradition.

* *Seismos*, Greek for earthquake: seismology is the science of earthquakes. A seismometer is an instrument for recording such movements and measuring their intensity.

Between the years 1865—1885, Dr. Fuchs* notes nearly 8,000. Yet with the exception of the Peruvian one of 1868, which led to the loss of over 100,000 lives (Fig. 112), that of Granada in 1875, those of Peru in May, 1877, and January and February, 1878, and those of Chios (1881) and Andalusia (1884), not a great number could be described as being in the first order of such catastrophes. It has, moreover, been noticed that earthquakes, like volcanoes, have a certain periodicity. These periods may occur in regions where earthquakes are rare, as well as in those where they are frequent, and, after remaining undisturbed for many decades, a district may be suddenly convulsed by the most violent shocks.

Seismic Waves.—The accurate instruments which have been invented of late years enable us to notice and record features of earthquake disturbances which were formerly missed. The result of the activity of the last few years—especially in Japan, where the labours of Professors Milne, Ewing, Gray, Skida, and Chaplin, have almost revolutionised former ideas on the subject—has been to prove that during an earthquake there is a number of successive vibrations. In some cases as many as three hundred have been distinctly registered. These vibrations are irregular, both in period and amplitude—or deviation from the normal—and the amplitude does not exceed a few millimètres,† even when the earthquake is of sufficient severity to throw down chimneys and crack walls, while in many instances the greatest motion is no more than the fraction of a millimètre. "The periods of the principal motions are usually from half a second to a second, but the early part of the disturbance often contains vibrations of much greater frequency. The earthquake generally begins and always ends very gradually, and it is a noteworthy fact that there is in general no one motion standing out from the rest, or greatly larger than those which precede and follow it. The direction of motion varies irregularly during the disturbance, so much so that, in a protracted shock, the horizontal movements at a single station occur in all possible azimuths.‡ The duration—that is to say, the time during which the shaking lasts at any one point—is rarely less than one minute, often two or three, and in one case in the writer's experience was also as much as twelve minutes."§ These observations specially apply to the Japanese earthquakes; but, with modifications, they hold true of terrestrial tremors everywhere else.

It is thus clear that, contrary to the belief on the subject, the earthquake motion is not always in a determinate direction. In one felt at Tokio on the 8th of March, 1881, the horizontal path was almost circular, though the time occupied from the beginning to the end of the vibration was only three seconds, and it did no damage except to crack a few walls. The wave passing through the crust displaces a certain portion of the ground; to this the cracks in the earth, and the damage to the buildings on it, are due. But just as observers often differ widely amongst themselves as to the direction of the prevailing oscillation, so they do regarding the magnitude of the displacement of the ground. This is generally much exaggerated. In the great Neapolitan earthquake of 1857 (Fig. 113) it is said to have amounted to a foot; and in the Manila earthquake of 1881, Abella assigns six feet as the amplitude. But such displacements must be rare, for when the motion is as much as a quarter of an inch, brick and stone chimneys are generally shattered. At the same time the automatic seismographs have never yet recorded any great shocks; and, as the apparatus would most likely be thrown out of gear by a disaster of any magnitude, it is not probable that in future we shall be able to dispense with guesses founded on the misconception of observers, who in the turmoil of an earthquake are not very well fitted to weigh facts calmly.

* *Sitzungberichte der K. Akademie der Wissenschaften in Wien, Oct.*, 1886.

† A millimètre may be taken as one twenty-fifth of an inch.

‡ That is, to all points of the compass.

§ Ewing, in *Memoirs of the Science Department of the University of Tokio*, No. 9, 1883, p. 13; George Darwin, in *Fortnightly Review*, February, 1887, pp. 263—275.

After an earthquake the survivors who favour the newspapers with their experiences generally describe themselves as having suffered the sensation of being tossed about. Every railway traveller knows that it is not the steady speed, but the starting and stopping, which jar him. That is to say, it is the change of velocity by which he is shaken. In like manner, as Professor George Darwin points out, the misconception of an observer in an earthquake arises from the fact that the sensation of being "tossed about" comes from the change of velocity to which he is subjected, rather than from the extent of his displacement. "The greatest change per second of velocity may be considerable in a vibration whilst the amplitude is small." This delusion is assisted by the appearance of the scene around the observer. Spires are swaying, and, as in Calabria in 1783 and Missouri in 1811, the trees are often so much depressed that the boughs, when they reach the ground, break off, and forests or groves are noticed to wave to and fro like a field of corn before a breeze.

Professor Milne, by explosions of gun cotton in holes in the ground and by the fall of heavy weights, produced small artificial earthquakes. From these experiments, and actual facts observed during the many earthquakes with which Japan is shaken, he has come to the conclusion that earthquake waves consist of two kinds of oscillations, namely:—(1), waves or vibrations of compression; (2), waves or vibrations of distortion. In the first kind the motion of each particle of the ground is to and fro in the direction in which the wave is travelling; and in the second kind, the "excursions are at right angles to the direction of

Fig. 113.—STREET VIEW IN POLLA (THE ANCIENT FORUM POPILII), AFTER THE EARTHQUAKE OF 1857.

(From an Engraving in "The Great Neapolitan Earthquake of 1857," by Robert Mallet.)

wave propagation. As the former vibrations travel more rapidly than the latter, all the compressional waves may have passed a given station before the arrival of the distortional waves, and thus the shock may be apparently duplicated. Or, nearer to the origin, the two series will overlap, and a complex movement ensues." Reflections and refractions as the waves pass from one geological stratum to another further complicate the phenomena. But "the rate at which these waves travel depends on the nature of the rock through which the movement passes." Mallet found that in solid granite the rate was about 1,666 feet per second, while in wet sand it was as slow as 825 feet per second.

In hard rocks the fissures are narrower, and they close more quickly than in soft ones. Hence less displacement is caused, and naturally less destruction. It is also noted that when a wave passes from compact into loose rocks, the complexity caused by "reflection and reverberation of shocks" tends to a more destructive shattering of the surface than breadth. Within these bands the seismic influence is felt for a distance varying from 5 to 15 degrees of longitude, while outside these areas, shocks are rare and of attenuated character. These seismic bands very frequently follow the lines of elevation which mark and divide the great oceanic or terr-oceanic basins of the earth's surface, and if these happen to be mountain chains, then the seismic bands follow these likewise, especially if (as is frequently the case) such chains contain volcanic vents. Finally, though seismic energy thus becomes sensible at any point of the earth's surface, its efforts become greater as the chief lines of volcanic activity are approached, while the width of these seismic bands depends upon "the energy developed, and on the accidental geological and topographical conditions along its length." The initial point of the wave or succession of waves traversing the earth's crust which constitute a shock is at some depth in the subterranean world (Fig. 114). This "centre of impulse" is often beneath the sea, but in

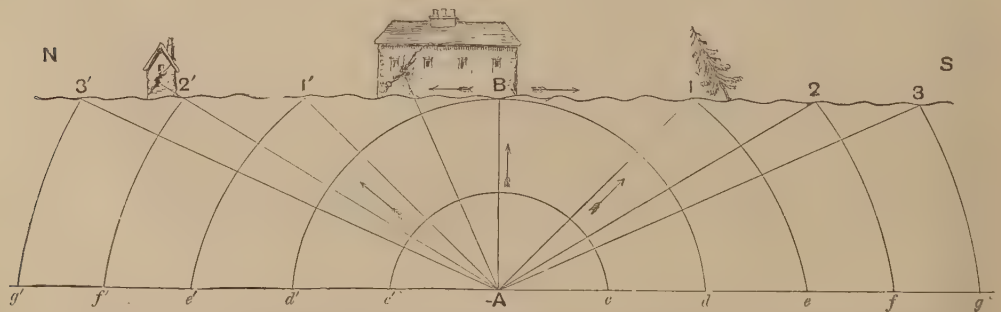


Fig. 114.—DIAGRAM ILLUSTRATING MALLET'S THEORY OF THE DIRECTION OF MOVEMENT FROM EARTHQUAKE FOCUS.

A, Earthquake focus, or centre of impulse; B, Seismic vertical. The lines A1, A1′, A2, A2′, A3, A3′, represent the direction of the movement from A. The position of circles shows the depths at which the shock would be felt at the same time—*i.e.*, the particles would move on the lines *c c′*, *d d′*, and so on, as if these were sections of hollow shells placed one over the other. The wave would reach the surface first at B, and travel from it north and south, occurring simultaneously at the coseismic points 1 and 1′, 2 and 2′, 3 and 3′ (See also Fig. 115.)

could have ensued had the wave continued its course through the same kind of stratum.

Origin of Earthquakes.

Mallet finds that the areas of the earth most frequently and violently disturbed by earthquakes form bands of great but variable

Japan it is seldom that the waves cross through the mountains forming the backbone of the islands.*

* Milne: "Earthquakes and other Earth Movements," p. 189. Observations to the same effect have been made in other parts of the world, but the seismic waves, though modified, were not, during the Charleston earthquake of 1886, stopped by the intervening mountains.

Where the centre of impulse is we can only infer with any approach to accuracy. Mallet considered that the Calabrian shock of 1857, which destroyed so many towns, originated between three and seven miles below the surface (Fig. 116). That of Herzogerath (1873) was believed to have originated fourteen and a half miles below, while one at Belluno was estimated by Höfer to have begun over four miles beneath the

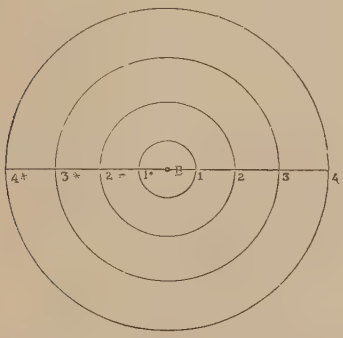


Fig. 115.—DIAGRAM OF SEISMIC CIRCLES.

B, Seismic vertical; 1 1*, 2 2*, 3 3*, 4 4*, Coseismic points on seismic circles.

earth's surface. The Yokohama earthquake of 1880 seems to have had its centre at a depth of from one and a half to five miles, and in one case it is believed that the initial point of the earthquake was fully fifty miles beneath the surface, though, as a rule, the centre of most shocks is not more than a few miles in the crust which they shake. Seismologists are, moreover, beginning to hold the opinion that the shocks do not "usually originate in a single point, but rather along a line of a mile or two in length." Hence the vagueness with which the position of the centre of disturbance—or "centre of impulse," to use Mallet's expression—of particular earthquakes has been assigned.

But be the focus where it may, the waves proceed thence with equal velocity in every direction. The line along which the wave reaches the surface—or "epicentrum"—directly over the "centre of impulse" has been called the "seismic vertical," and the concentric lines along which the shock reaches the surface at the same moment the coseismal lines," though the wave strikes the surface more and more obliquely as it recedes from the seismic vertical, and with less and less force, till it gradually fades away (Fig. 115).*

Causes.—What actually originates the shock is still a mystery, and, from what has already been said regarding the origin of volcanoes and geysers, it is tolerably apparent it is never likely to be anything else. The underground noises which immediately precede a shock have been variously likened to chains pulled about, to the rumbling of carriages, the roll of thunder, the discharge of a park of artillery, heavy waggons running in a road, the hissing produced by the quenching of red-hot iron in water, the rush of wind underground, "the rumble made by heavy ore teams in passing;"† and in the Charleston earthquake of September 2nd, 1886—the origin of which was calculated to be at about twelve miles beneath the surface, and the wave of transmission to be propagated at the rate of over three miles a second‡—most observers noted merely a "rumbling sound," as either preceding, accompanying, or succeeding the shocks which occurred on that day, or followed on subsequent days (Figs. 126, 127, 128).

On the other hand, many earthquakes are not accompanied by any underground sounds. Of this character was that which on the 23rd of February, 1887, shook the coast district of France and Italy known as the Riviera (Fig. 117), and extended across the Atlantic with sufficient intensity to disturb the instruments in the Washington Observatory, the rate of travel being about 500 miles an hour. Again, in South America and elsewhere underground sounds are often heard without earthquakes following in their immediate train.

These facts, therefore, tend to show that the force which generates the earthquake must, in some instances, be so sudden that it gives

* "First Principles of Observational Seismology," cited by Jukes-Browne, *l. c.* p. 38.

† This is the simile used by Mr. Goodfellow in his description of the Sonora earthquake of May 3rd, 1887 (*Science*, Vol. IX., No. 224, p. 483).

‡ Dutton and Hayden in *Science*, Vol. IX., No 224, p. 489.

no premonitory intimations of what is coming—in other words, it is not preceded by any preliminary minor disturbances of any sort; or, owing to the resisting character of the medium through which the sound is propagated upwards, the sound does not reach the ear. Nearly all theories regarding the cause of earthquakes, however, agree in considering them due to some such hypothetical explosions—closely akin in their nature to those which generate volcanic eruptions. Among the many hypotheses which have been proposed, that of Mallet for long received very general support. (1), He assumes the internal molten centre of the earth for granted. Then when water enters through the fissures in the crust, made when there is a volcanic discharge under the sea, it first assumes the spheroidal condition, in which state little steam is generated, and therefore no impulse is imparted to the crust greater than what is sufficient to generate the tremblings which so generally precede the main shocks. But when the heated surfaces cool, the water being able to come into closer contact with them evolves vast volumes of steam, which, blowing off into the deep cold water of the sea, gets condensed, and thus imparts a violent blow at the volcanic focus, which being transferred outwardly in all directions is transmitted through the crust in the form of the familiar earthquake tremors. The gentler tremblings after a shock are regarded as due to the feebler discharges of steam from the comparatively cool surfaces. But when the surfaces again become heated from the molten mass, the phases described may begin afresh. At the same time, while regarding the circumstances mentioned as the

Fig. 116.—CATHEDRAL OF TITO, SHATTERED BY THE EARTHQUAKE OF 1857.

(*After Robert Mallet.*)

principal causes of earthquakes, Mallet is willing to grant that some of them may be due to "the evolution of steam through fissures and its irregular and *per saltum* condensation under pressure of sea-water; or to great fissures and dislocations in the rocky crust, suddenly produced by pressure acting on it from beneath, or in any other direction."

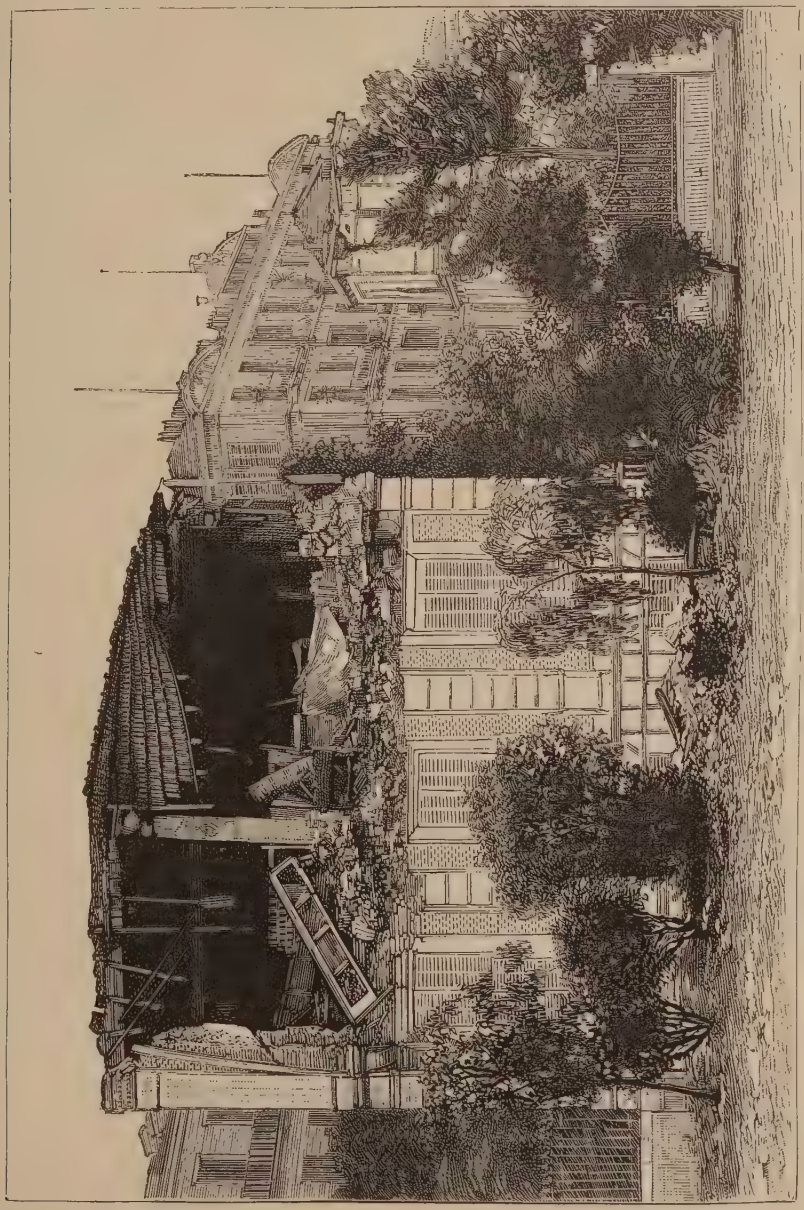


Fig. 117.—HOUSE IN THE AVENUE DE LA GARE, MENTONE, RUINED BY THE RIVIERA EARTHQUAKE (1887).

(2), This, to some extent, accords with the theory which regards earthquakes as movements "caused by a shrinking from loss of heat of the heated interior of the earth and the crushing together and displacement of the rigid exterior as it accommodates itself to the contracting nucleus,"* which we have seen has been invoked to account for more than one phenomenon in the earth's history (pp. 85, 175, 189).

(3), It is also more than probable that some earthquakes are mere local collapses of the crust from the underlying rocks being dissolved out by water, or other causes. This seems to have been the real origin of the "earthquake"—if it can so be designated—which destroyed so many buildings and caused so much loss of life on the Island of Ischia in the year 1883,† and of those minor tremors which are of constant occurrence in the honeycombed limestone district of the Karst, north of Trieste. In the Visp Valley in Canton Valais (Switzerland), continued rumblings and sharp shocks lasted for upwards of a month in 1855; but these earth movements, though of sufficient intensity to fissure buildings and cause many of the ordinary results of earthquakes, are believed to have been due solely to the subsidence of the crust overlying strata rendered unsubstantial by the numerous springs which dissolve out the gypsum with which they are permeated. This cause can, however, have only a local bearing, unless indeed we believe that the earth is like a Gruyère cheese, full of cavities, constantly falling in, or with their gaseous contents often exploding.

(4), Professor Milne seems to incline to the belief of the Continental geologists, that earthquakes may be due to the breaking of strata while mountains are being tilted up owing to the secular cooling of the earth, as well as by underground explosions of steam. Possibly many of the earthquakes of Central Europe may, as we shall see (pp. 252–5) when we discuss the effects of shocks, be due to this cause,‡ and it is likely that many of those of India and other mountainous regions may be traced to a similar uneasiness in the earth's crust, due to this sinking down with the object of accommodating itself to the contracting nucleus. But in Japan and most other extremely volcanic centres, the explosions of steam from water which has found its way into the earth from the rainfall or from the sea must be regarded as the principal agents in the many convulsions to which volcanic tracts are specially subjected.

(5), In addition to the causes here enumerated, there may, doubtless, as Professor Shaler seems to think, be earthquakes due to the rush of imprisoned lava through the earth's crust in filling up the rifts which we know as dykes—this action being at work now as well as in the past,—though this cause may be properly bracketed under the head of volcanoes and their connection with earthquakes. Minor or local earthquakes may also possibly be produced in cold countries when the frozen ground rives asunder owing to the expansion of the contained water in freezing. The crevice may be but a fraction of an inch wide and a foot or two deep, yet the ground is often so violently jarred that a sensible earthquake is produced, which may be felt hundreds of feet away from the source of disturbance. Indeed, a comparatively slight shock vibrates through the earth's crust for very great distances. The mines used for the blasting of the reefs at Hell Gate, near New York, in 1886, though trifling compared with the great steam explosions in the earth's interior, generated a shock which was distinctly perceptible 100 miles from the point where the blow was struck, and faintly at nearly double that distance.

(6), Lastly, we may notice the theory proposed by the brothers Rogers. They regard the actual pulsation in the fluid matter beneath

* Newberry: "Earthquakes" (1886); Hörnes, in *Jahrbuch der K.K. Geol. Reichsanstalt* (1878), p. 448.

† Johnston—Lavis: "Monograph of the Earthquakes of Ischia" (1886); Fuchs: "Monog. Geol. dell' Isola d'Ischia" (1873); Fonseca: "Geologia d. Isola d. Ischia" (1870); Mercelli: "Vulcani e Fenomeni Vulcanici in Italia" (1883); and "L'Isola d. Ischia," etc. (1884).

‡ Suess: "Entstehung der Alpen" (1875); Schmidt: "Studien über Erdbeben" (1879); Fuchs: "Les volcans et les tremblements de terre" (1887); etc.

the crust, "propagated in the manner of great waves of translation from enormous ruptures, caused by tension of elastic matter, and floating forward on its surface the superimposed rocky crust of the earth," as accounting for the phenomena of earthquakes, and confirmed by the features presented by various mountain ranges like the Appalachians. The main difficulty in this hypothesis is, that no such "pulsation" has ever yet been even remotely shown to be probable, any more than the tidal waves in the earth's crust (which also have been suggested) can be shown by anything like proof to exist. Moreover, these theories demand the admission of a liquid interior—a demand which at once rules it out of court in the eyes of those who insist on the non-existence of such a condition of the subterranean world. Indeed, the fact of our old ideas on this subject having been unsettled by the promulgation of a doctrine so absolutely the antipodes of the one which it is intended to displace, has not improved the facility with which theorists explain volcanoes and earthquakes. The probabilities, however, are that they may be due to a variety of causes, and that, in spite of all that has been said against it, shrinking due to contraction may be one potent factor in precipitating some, while the explosion of steam, in one of the various ways suggested, may be the cause to which we must look for the explanation of others which cannot well come under the former head.

It thus appears that, in the present state of our knowledge we can no more attribute earthquakes to one cause than we can volcanoes. Indeed, as the reader must already have been led to see, all speculation on the subject is, and must be, purely conjectural, and the man who insists that any particular dogma affords the key to the solution is simply deceiving himself and his readers.

That there is some connection — a very close connection, indeed — between earthquakes and volcanoes cannot, however, admit of any doubt; yet what this exactly is we cannot affirm with confidence. All volcanic countries are also earthquaking; but, we have already seen (p. 227), all earthquaking regions are not volcanic. Spain and Portugal, for example, are not the seats of active volcanoes; and the United States are, in the region most recently affected, equally clear of volcanic vents. Britain is also a region of mild earthquakes; so is Hungary; yet neither is a land of active volcanic action. Even in Japan—a land of extreme volcanic energy *—volcanoes cannot be described as the direct causes of the earthquakes, for 80 per cent. of them come from the sea-board—many of them from the sea itself—while the shocks are generally felt on one side of a volcano only.

Quasi-scientific Theories.—This being the case, it is not necessary to more than refer to many other quasi-scientific theories which have been put forward with the object of solving the problem. Not to mention the mythical demons and not less fabulous deities moving uneasily under the surface—a doctrine held to this day by many savage and semi-barbarous peoples—the notion of subterranean winds—an idea not improbably suggested by the rushing sound of the premonitory noises (p. 231)—being the primary causes of earthquakes was held by Aristotle, Pliny, and other ancient writers, and obtained a classical sanction from Shakespeare.† Indeed, it maintained its ground in England well up to the middle of last century, when it was displaced by the electrical theory. Even yet this extremely hypothetical notion is entertained by people who might be supposed to know better. Stukely, Percival, and Priestley, advocated the idea of earthquakes being in some way, not very clearly explained, caused by electrical currents, and in California to this day it is quite common to hear that since the State has

* In the Japanese Islands there are 48 active volcanoes, and 83 regarding which records of eruptions exist, or which have evidently been active in recent times, as shown by their solfataras. In the five years between 1876 and 1881 Tokio experienced 377 earthquake shocks.

† "Diseased Nature oftentimes breaks forth
In strange eruptions; oft the teeming earth
Is with a kind of colic pinched and vexed
By the imprisoning of unruly wind
Within her womb; which, for enlargement striving,
Shakes the old beldam earth, and topples down
Steeples and moss-grown towers."—1 HEN. IV., iii., 1.

been intersected by railways, the "dangerous electrical accumulations" being diverted from the soil, earthquakes have been largely reduced; and theorists have not been lacking who, without producing any proof in support of their assertion, have predicted that the same will hold true of Japan when iron-ways spread over the islands. Nevertheless, it is well known that electrical phenomena do accompany earthquakes, affecting telegraphic cables and lines, and that in Mauritius earth currents have been found to precede the shocks so frequent in that volcanic part of the world. In Japan also, there are cases on record in which earthquakes were either accompanied or preceded by abnormal earth currents. But all evidence and reasoning thus far adduced tend to show that such currents are a consequence, rather than a cause, of conditions producing earthquakes.* How far, if at all, particular atmospheric states influence or precipitate earthquakes may be best discussed when we come to consider the possibility of forecasting the occurrence of these phenomena (p. 256).

Distribution of Earthquakes.

While it may be taken for granted that no large area of the earth's surface is ever entirely free from tremblings, there are grounds for believing that not only are certain regions more subject to earthquakes than others, but that there are certain periods of time when these phenomena are more marked than at others. For example, to go no farther back than the last few years, the globe has shown that it is losing little of the Titanic vigour of her youth, or, at all events, that, in what some philosophers have described as her feeble senility, the earth is quite capable of efforts equal to anything which we have reason to believe was witnessed in the past. Volcanic disturbances have followed each other in rapid succession. First came the gigantic explosion of Krakatau, the greatest within the memory of history, and before long both Etna and Vesuvius were in eruption; while the neighbouring region was more or less disturbed by tremors of its crust; and the extraordinary outbursts of New Zealand, Tonga, and the Sandwich Islands, have happened in such rapid succession, that before we have had time to fully appreciate one, many others have been reported. In March, 1881, Casamicciola was almost entirely destroyed by an earthquake, and a month later the island of Chios was nearly ruined by a similar misfortune. The same year saw Agram convulsed with serious earthquakes, and then the south of Spain suffered even more severely. The Alps, various parts of Italy, and the Greek Islands were the next to be attacked, and the tremors which shook so many hundred square miles of Greece seem to have crossed the Atlantic and laid the city of Charleston in ruins. In 1887 we had the Riviera shocks, and a few months later many districts of Northern Mexico, Arizona, and a large area of Central Asia, were shaken. Altogether, without going into details, it is certain that of late there has been an unusual period of subterranean activity over a very wide region of the world, even if we do not always grasp the relation between such circumstances as the eruption of some of the Kamtchatka volcanoes, about three months before the great Krakatau explosion.† They may be coincidences, or they may have the connection of cause and effect. Still, it is possible to mark out several broad bands which may be considered the proper home of earthquakes. These bands (Fig. 118) have a tendency to pull "end to end," so that, as Professor George Darwin puts it, they may be regarded as a single ribbon embracing half the earth, and which it may be suspected really meets itself and forms a closed curve. This, however, cannot as yet be proved. If we begin to trace its course at Cape Horn, it will be found that it follows the Andes along the whole western side of South America—and this comprises some of the most notoriously earthquake-shaken regions of the world. It then broadens out, and passing along the line of the West Indies from Trinidad to Cuba,

* The *Times*, January 7th, 1887.

† Guillemard: "Cruise of the *Marchesa*" (1887). Vol. I., p. 343.

Fig. 118.—EARTHQUAKE MAP OF THE WORLD.

crosses over to Mexico, and takes in the whole of the western slope of the Rocky Mountains, on to Alaska, from whence it passes by way of the volcanic chain of the Aleutians over to Asia, where, in Kamtchatka, the Japanese Islands, the Philippines, the Moluccas, Sumatra, and Java, it finds a home in a part of the world where volcanoes are frequent. From Java another branch takes its way through New Guinea to New Zealand, and it is quite possible that the closed curve may be completed by the Antarctic regions, which we have seen are volcanic. But this it is still impossible to assert for certain, as these lands are almost entirely unexplored.

To the west of Java the seismic region is less continuous, though the ribbon may be traced through India, Persia, Syria, the Eastern Mediterranean, Greece, and Italy. In other words, the Old World region of earthquakes is mainly between the Alps and the mountains of Northern Africa, its eastern limits taking in the Mediterranean, and the inland seas to the east, on to the mountains of Central Asia; while the New World area increases in intensity from the Atlantic States, which are occasionally affected, to the Pacific, the entire area of which and its land borders are, either inferentially or actually, the seat of severe seismic disturbance. We might therefore say, in general terms, that the range of earthquakes is practically the same as that of volcanoes, though, of course, there are mild shocks in lands where there are no craters either dormant or active. All that is meant by the "seismic bands" is that they mark out the "one great principal line of cracking of the earth's surface." Professor Darwin, however, while thus contending for a continuous band of seismic action, admits that the disturbed areas are not absolutely constant in their limits, and cases are known where regions previously almost quiescent have become disturbed. Charleston is a case in point, the previous tremors in South Carolina having been rare and comparatively mild. In reality, the earthquake which wrought such damage to the South Carolinian city (Figs. 126, 127, 128) may more appropriately be regarded as an extension from the West Indian area of seismic activity, and though a recurrence of slight shocks may be expected for a year or two, it is likely to remain a unique occurrence. Prior to the great Lisbon earthquake of November 1st, 1755, that town had been visited by shocks of greater or less intensity. But these were almost forgotten when in a few minutes the city was laid in ruins, and between fifty and sixty thousand people lost their lives by this sudden catastrophe, the like of which has never been paralleled in modern times. The city of Fez in Northern Morocco was so violently affected that, it is affirmed by the Moorish historians, 12,000 people perished. Setubal was almost entirely destroyed, a large part of Malaga was ruined, and Coimbra, Oporto, and Baya, all suffered to a greater or less extent, while the island of Madeira was laid waste, and in the Greek Island of Mytilene more than 2,000 houses were overthrown. This shock was felt as far north as the Scandinavian Peninsula, and as far east as North America. Yet, while Loch Lomond in Scotland was so influenced by the seismic wave that its waters rose and fell convulsively, the earthquake does not seem to have been noticeably felt in England,* most probably owing to the fact that the wave travelling through hard rocks at a great depth below the ground, "the slight shock communicated to the thicker mass of softer rocks which form the greater part of England died away before it reached the surface." Much the same fact holds true regarding other earthquakes, and it is believed that the one which did such damage to Charleston would have been infinitely more disastrous had not the city been underlaid by quicksands, which being an imperfectly elastic material, rapidly extinguished the energy of the shocks which, moreover, though reaching nearly a thousand miles away from their centre of origin, were at their point of greatest intensity more than ten miles distant from Charleston. Yet from 1755 to the present hour Lisbon has been rarely affected by a

* Peerless Pond, near the City Road, London, is said to have been agitated.

seismic wave. Several shocks, mostly of no great severity, have occurred. In 1847 the royal family fled from the palace, in the vicinity of which fissures from one inch to several feet wide opened. But very little damage has been done.

The only other point which has been ascertained with anything like certainty regarding the connection of earthquakes with geological structure is, that they generally follow lines of faulting (p. 252), and that therefore the "seismic ribbons" may not unlikely be "lines of weakness along which cracking habitually takes place." For this, or for some reason which has not yet been hit upon, certain regions are more liable to disturbance than others, and in Japan, where there is on an average at least one earthquake every twenty-four hours, some spots are notoriously subject to shocks. Mr. Milne mentions a princely mansion at Tokio "which has so great a reputation for the severity of the shakings it receives, that its marketable value has been considerably depreciated, and it is now untenanted."*

Intensity of Earthquakes.

The violence of a shock, or series of shocks, which, combined, we know as an earthquake, varies from the faintest tremor barely perceptible by the seismograph, which automatically records the oscillation of the ground, to the most violent of which history has preserved any record. The Swiss Commission appointed to investigate the subject has drawn up a scale which is useful for recording, approximately at least, the degree of intensity exhibited by any earthquake. It is as follows, the graduation, however, being inverted :—

(1), A great calamity: ruins of buildings, falling of rocks, upheaval and gashing of the earth, and fall of cliffs and even of parts of mountains, while the soil covering of the earth is "shaken as in a sieve." Of this group, the great earthquakes of Peru, and of Lisbon and Calabria, and those of New Madrid, in Missouri, may be taken as examples.

(2), Partial or entire destruction of buildings, or in which all except the strongest edifices are overthrown, "great pinnacles of rock overturned, and the soil rent by occasional fissures." To this group the Charleston earthquake, and those of Greece, Agram, and Spain, already referred to, belong.

(3), Falling of chimneys, splits in walls or buildings, when the latter are of an old or weak character, but with "the natural features of the surface not much disturbed." In this group Professor Shaler places the Massachusetts earthquake of 1755. Those of Essex in April, 1884; of the Riviera in 1887 (Figs. 119, 121, 122); of Visp, in Valais, Switzerland, in July, 1855, also felt in Paris; Grossgerau, in Hesse, in 1869; and of Klana or of the Karst, which lasted from the 27th of February to the 8th of July, 1870, may also be placed under this head, though it is not always possible to exactly allocate each earthquake to the classes thus systematised.

(4), Falling down of movable objects, breakage of plaster from the walls, ringing of church bells, and general terror; but no damage to buildings, and no distinct influence upon the natural features of the earth's surface.

(5), Universal awakening of sleepers, general stoppage of clocks, ringing of house bells, smashing of candelabra, glass, and crockery, and visible oscillation of trees, bushes, and spires, when very narrow and high. It may be added that when the earthquake is of this degree of intensity there is a general rush from the houses, camping out in the squares and fields and what the Americans know as "demoralisation" of the population. In Charleston the negroes were especially subject to panic; and in Spain—though the churches were not crowded, owing to dread of the roofs falling—the images of saints and all open-air shrines were surrounded by devotees.

(6), Movements of the earth producing some alarm among the population of cities and disturbance of furniture, beds, ringing of house-bells, etc., as if a very heavily-laden waggon had passed at great speed along the street outside.

* "Earthquakes and other Earth Movements" (1886), p. 134.

(7), Slight movements affecting persons in the near neighbourhood of the centre of origin, and shaking of various objects, such as windows, doors, loose or split boards, etc.

(8), Slight motion followed by a period of silence, the direction and duration of the wave being unascertained.

(9), Shock only ascertainable by means of the seismograph, followed by a subsequent period of quietude.

(10), Minute motions that can only be registered by the best-constructed instruments.

Yet even these numerous gradations of earthquake intensity do not exhaust the mobility to which the unstable globe is subject. Recent observations, indeed, go far to demonstrate not only that the earth is in some place or other being continually shaken by more or less perceptible tremors, but that at almost any spot, even in regions which are not known to be liable to such commotions, the soil is in a continual tremor, like a mass of jelly on a table when heavy footsteps are passing across the floor. Not only is the ground subject to what Mr. Milne has called "earth pulsations"—or temporary swayings of the earth so slow that, though occupying from a few seconds to a few hours, they do not give any sense of shock, and can best be observed by means of delicate spirit-levels, the bubbles of which move with very slight changes of level at either end of the instrument—but to rapid motion in almost every second of time. There are also "seismic storms," or periods when the terrestrial agitation is more intense than usual, the storm sometimes culminating in a shock which can be perceived without instruments. Then a period of relative quiescence ensues. The vibration of the instruments devised to record these movements is, in general, parallel to neighbouring valleys or chains of mountains, and, though seemingly independent of wind, rain, and temperature, is especially apt to be intense when the barometer is low. These "microseismic" storms, Professor Darwin notes, are not strictly simultaneous at different places, though there is a close agreement between those which occur in Italy, where—owing to the enthusiasm of Bertelli, Rossi, Malvasia, Monte, Cecchi, Palmieri, Egidi, Galli, and others—great attention has been paid to this curious branch of seismology. By calling in the help of the microphone, the commotion made by these movements can be heard. When this instrument was placed in a cavern sixty feet below the surface of Rocca di Papa, an extinct volcano not far from Rome, Rossi heard the most extraordinary sounds—"roarings, explosions, occurring isolated or in volleys, and metallic or bell-like sounds"—all mixed together, and rising and falling in intensity at irregular intervals. Microseismic motions and seismic storms have also been observed by the brothers Darwin in England.*

How these "microscopic earthquakes" are caused has still to be ascertained. It is possible that they are due to movements in the immediate neighbourhood, or more probably they are the reverberations of very distinct shocks. In the vicinity of a dormant or extinct volcano they may be simply the uneasy movements of the imprisoned forces, labouring to renew their quondam activity. One hour and fourteen minutes subsequent to a very severe shock at Iquique, in Peru, the instruments in the St. Petersburg Observatory were agitated. Astronomers are also well aware that the piers of their instruments undergo slight changes of level, or "displacements of the vertical," though they are still, in spite of the many observations which have been made on the subject, unable to satisfactorily explain it. When, however, we know the almost continuous series of earthquake shocks, perfectly noticeable to the senses, which are going on, and that many regions of the world are slowly rising and falling, we need not be surprised that "microseismic" tremors are observable in the earth's crust. The wonder would be were they not present. The weight of the sea—which, according to Professor Darwin's calculations, is, on every square foot of the bottom, 620 lbs. (more at

* *Report to the British Association on Lunar Disturbances of Gravity*, 1881; *Fortnightly Review*, February, 1887.

high than at low water), or nearly eight million tons to the square mile—may likewise have something to do with this obscure subject. As for the "earth pulsations," while it is quite possible that they depend in part upon changes in the atmosphere, they may, as Professor Shaler suggests, be due in part to the varying strains which are produced by the continent and mountain building processes (p. 187), and perhaps in certain regions near the shore to the action of the volcanic forces as well. It may also happen that these minute tremors are in some instances due to the motion of their particles, which occur in rocks during the process of metamorphism (p. 110). As the "microseismic" movements often precede the greater ones, in time they may be utilised as warnings of what is to come.

Fig. 119.—HOUSE IN NICE, DEMOLISHED IN THE RIVIERA EARTHQUAKE (1887).

CHAPTER XIII.

Earthquakes: their Influence on the Structure of the Globe, etc.

Rapidity of their Effects—The Earthquake Wave—Its Destructiveness—Examples from Lisbon, Peru, Hawaii, and Sicily—Fissures in the Earth's Crust—Tumbling down of Cliffs and other Geological Features—Changes of Level—Examples from New Zealand, Chili, Italy, and India—Interference with the Drainage—Formation of Fissures—Dislocation of the Strata—Ideas of Suess and other Geologists regarding the relation of Earthquakes to Faults, caused by the Subsidence of the Earth's Crust to accommodate itself to the shrinking nucleus—Examples from Switzerland and Tyrol.

The course which an earthquake runs is usually very rapid. From the moment when the first shock was felt at Lisbon to the period when all was over, and nearly 30,000 people were killed,* not more than four minutes elapsed. A few seconds are usually a more frequent time for the shock or shocks to last. Yet, while Caracas in Venezuela was almost destroyed, and 12,000 of its inhabitants killed by the earthquake of 1812, within the limits of half a minute, there are cases in which constantly-recurring shocks last for weeks, months, and even years, as if the labouring earth was still trying to relieve itself of some of its superabundant energy. For example, the Calabrian earthquake of February, 1783, was not quite finished before December, 1786, and it is a common observation that the preliminary shock is usually followed by one of greater severity, and this in its turn by others less intense, like the distant claps of thunder which herald the passing storm. But in this brief span the most frightful havoc can be wrought, and the wave of destruction propagated from the most distant regions. The rumbling earth sound travels, for instance, at the rate of 10,000 or 11,000 feet per second, and the earth wave, on an average, about 1,200 feet in the same space of time, though in Charleston, as we have seen, a much higher rate was attained (p. 231). But if the terror inspired by earthquakes and the sickness produced by the swaying motion are sufficiently alarming, the after effects, of even the slightest of these tremors, are sufficiently terrible to cause all the dread which their recurrence inspires in the minds of even those familiar from childhood with their results.

The Earthquake Wave.—In earthquakes originating under the sea, the wave of water propagated outwards, and sweeping far inland with relentless force, is, to the regions lying near the shore, perhaps the most destructive of all the after effects of a shock. It is generally known as the "tidal wave," but in truth it has nothing whatever to do with tides, and is really a wave of displacement. When the shock occurs the sea is, as it were, sucked back from the shore, and then returns in a wall of water which rushes inland, sweeping before it men and cattle, trees and houses, to be followed at intervals by smaller waves. The velocity with which it travels depends, first, on the force of the propelling shock, and secondly, on the depth of the sea, the wave being propagated much more quickly through deep than through shallow water. An earthquake wave surged across the North Pacific from Japan to California at the rate of more than six miles a minute, and from the time at which the sea wave from the Lisbon earthquake was noticed at the mouth of the Thames, its speed must have been a little over two miles a minute, though, on the other hand, it crossed the Atlantic to Barbadoes at a speed more than twice as swift. In Lisbon probably more people were destroyed by the "tidal wave" than from any other cause;

* This number of people was destroyed in the first few minutes. But there were in all twenty-two shocks, with a loss of nearly 60,000 lives; in the city prison 800 were killed, and 1,200 in the general hospital.

while along the Pacific coast of South America, the coming wave is always more dreaded than the more immediate results of the shocks. In Peru especially has the wave been dreadfully destructive. On the 28th of October, 1746, Callao was so completely destroyed by one which followed the great earthquake of that date, that, to quote a contemporary Spanish account of the catastrophe, vast heaps of sand and gravel occupied the spot where it formerly stood, and, instead of a busy port, only a "spacious strand" extending along the coast remained. Towers and town—though the latter was on an elevation—fell before the prodigious force of the wave, which, after reaching a height of 80 feet, swept on towards Lima, carrying before it the ships in port and stranding them on dry ground far beyond the harbour. Only two great gates, and here and there some fragments of walls, remained to attest the extent of the calamity. In this flood were drowned all the inhabitants of the place, numbering upwards of 5,000, except some two hundred who managed to cling to pieces of floating wreck. Happily, the wave abated its force before it reached the capital, seven miles distant.

This great earthquake was preceded for some days by subterranean noises, and after the first shock, on the 28th of October, there were, in twenty-four hours, 220, the disturbance not finishing until the following February. On the 13th of August, 1868, an earthquake which nearly destroyed Arequipa was succeeded by a wave which overwhelmed Arica and Iquique; and on the 9th of May, 1877, nearly all of the southern ports had to bear the brunt of another. Some of the most remarkable results of the Krakatau eruption, so far as its human interest was concerned, were due to the earthquake wave which followed, Anjer (we have seen) being washed away, and Telokbetong, in Sumatra, being, among other places, almost entirely destroyed (p. 160).

The Sandwich Islands are equally subject to these after effects of earthquakes. One which swept in upon the western shores of Hawaii commenced to advance at 5 A.M. on the 10th of May, 1877, and continued till the following morning, alternately rushing in and receding once in ten minutes. About fifty houses were destroyed, and the little church was moved bodily for a distance of about 200 feet. "It travelled," one of the most accomplished historians of the island tells us, "with much dignity, tolling its bell as it went, and was scarcely injured at all." This, it has been suggested, was the same wave which overwhelmed Iquique in Peru, 8,000 miles away. If so, it must have travelled at the improbable rate of 450 miles an hour. In 1811 the water suddenly receded from Honolulu, leaving the harbour partially dry and the reef bare. "It quickly returned, but rushed out. This little freak occupied about forty minutes, after which the sea was as calm as before. At the same moment the tide suddenly rose at Lahaina or Maui, at a distance of 100 miles. It rose and fell repeatedly at intervals of four minutes, rushing over the reefs with furious noise. It was afterwards reported that a similar phenomenon occurred on the coast of Kamtchatka at the same time."* On the 7th of November, 1837, an earthquake wave even more remarkable was felt throughout the entire group, but most seriously in Maui and Hawaii, where it destroyed much property and many lives. At five in the afternoon, when everything seemed peaceful, and the islands were bathed in their wonted sunshine, the sea began rapidly to retreat from the shore, leaving the reefs entirely dry. Then suddenly, as the light-hearted natives were busy catching the stranded fishes, the water rapidly returned, and in half an hour rose to the highest tide mark. On a second recurrence the sea fell six feet, and then returned, and this "it continued to do with gradually decreasing force till noon on the following day." This was the general character of the wave at Honolulu. But on Maui it assumed much more serious proportions, the wave, on its first return, rushing in like a great wall of water, sweeping all before it, and overwhelming in a common destruction houses, canoes,

* "Fire Fountains," Vol. I., pp. 87–90.

cultivated fields, and whole villages. At Hilo it rose 20 feet above high-water mark, the break of this immense mass of water sounding, as an eye-witness described it, "as if a heavy mountain had fallen on the beach." Property of all kinds was swept out to sea. Not even a canoe escaped; and though the amphibious natives of the Sandwich Islands can generally hold their own in swimming, several were killed by being dashed against the floating wreck, or, unable to make headway against the violent suction of the advancing or retreating wave, sank exhausted in the water. Yet, curiously enough, it is especially noted by the Hawaiian chroniclers that except from the fact of the caldera of Kilauea having been in violent action on the previous night, there had been nothing unusual felt. An earthquake shock had not been experienced, so that the disturbance which had set in motion this vast mass of water—sufficient to sweep many isles at the same time—must have originated at a great distance in the least land-dotted expanse of the Pacific.

These facts regarding earthquake waves hold generally true regarding most parts of the world in which they have been experienced. In the Mediterranean waves have been felt with a force not quite so great as on the shores of countries bordering the Atlantic or Pacific, though, owing to the denser population of these regions, with a loss of life and property even greater. Scilla—the classical Scylla *—in the Strait of Messina, famous for its rock and the whirlpool of Charybdis, was visited by an earthquake wave after the shocks of February 5th, 1783, which, in the ruin it wrought, far surpassed anything which its "resonantia saxa" ever accomplished. After the first tremors almost the whole population of the place took refuge from their falling houses on the shore. But about eight in the evening, soon after part of Monte Baci, the next headland, fell into the sea, a huge returning wave rolled in upon the shore, engulfing in its water 4,000 people including the aged Prince Ruffo, who had prepared to pass the night in a boat drawn up on the beach.

In concluding these remarks upon earthquake waves, it may be useful to note the simple illustration of their formation which Professor Shaler, of Harvard, has devised. "Take a flat-bottomed wide pan of any sheet metal partly filled with water; let us strike it a sharp upward blow upon its base. We see that the water rises in the centre, and rolls off in a broad circular wave towards the margin. In the sea this wave may have a diameter of some scores of miles, though its height probably never exceeds a few feet. It is so wide and low, that as long as it is in deep water it may slip unnoticed beneath a ship; but when the front edge of the wave comes into the shallows near the shore, its advance is somewhat retarded by the friction of the bottom, while the part which is farther out to sea retains its swift motion. The wave is thus crowded into a less space, and so becomes constantly higher until, when it rushes on the shore, it may have attained a height of 50 feet or more." Yet though an earthquake wave thus does little or no injury to a ship out at sea, the crew of a vessel floating over or near the point where the "seismic vertical" reaches the surface—or the "epicentrum," as it has been termed—feel a sensation usually described as if their craft had struck a rock. Instances are known in which the ship has been dismasted or her seams opened by the blow. It is therefore not improbable that some vessels which have mysteriously disappeared have been overwhelmed by such calamities, what we know of the effect of submarine earthquakes being sufficient to show that escape from this final disaster must in not a few cases have been impossible.†

Fissures.—The earthquake wave, however destructive to life and property it may be, leaves behind it few, if any, permanent traces of its visit. It affects the earth in almost no appreciable degree, and therefore

* "Fell Scylla rises, in her fury roars,
At once six mouths expands, at once six men devours.
* * * * * * *
Ah, shun the horrid gulf! by Scylla fly,
'Tis better six to lose than all to die."
Pope's Homer's "Odyssey," Bk. XII.

† *Scribner's Magazine*, Vol. I. (1887), p. 278.

belongs more to the domain of history than to that of geology. But the earthquake does not permit the crust of the globe to escape scatheless. When a shock occurs, an upward jerk and an undulating motion are the movements usually recorded. The upward jerk cracks walls and rives the solid earth asunder (Fig. 120), while the rolling wave—or what seems such — rocks buildings, trees, and steeples, and, aided by the sudden shock, like that which is felt by the starting or stopping of a railway train (p. 229), commits the greatest amount of damage to property, and consequently to life and limb, by the falling of houses, cliffs, and high towers. The clefts formed in the earth will sometimes close after the motion has ceased and the utmost amplitude attained, though just as frequently they remain open, forming chasms of considerable breadth and depth, and often several miles in length, and, when one side of the crack is higher than another, constituting a dislocation or fault in the strata, like those of which we have already had so much to say (p. 80). At Lisbon, in 1755, hundreds of people and houses were swallowed up in the yawning fissures. The sea-port of Setubal, twenty miles south of the capital, wholly disappeared, and near the city of Morocco (Marakesch) the earth opened and engulfed a large and populous village, and then closed again. Many of the Portuguese mountains were riven from top to bottom, and huge masses of rock unloosened. In England, the old chroniclers tell of fields being shifted, and "great gulfs" opened during our many earthquakes.* At

Fig. 120.—VIEW NEAR THE NORTH END OF THE GORGE, BELLA, AFTER THE NEAPOLITAN EARTHQUAKE (1857). (*After Robert Mallet.*)

* O'Reilly : "Catalogue of British Earthquakes," *Transactions of the Royal Irish Academy* (1884), p. 285.

Port Royal, in the earthquake of June 7, 1692, whole streets, with the inhabitants, were swallowed up by the opening earth, "which," to quote a contemporary account, "then shutting upon them, squeezed them to death. And in that manner several are left unburied with their heads above ground; only some heads the dogs have eaten, others are covered with dust and earth by the people who yet remain in the place, to avoid the stench."* During the great Calabrian earthquake of 1783 (p. 239), during which 949 shocks were recorded, the pavements were thrown up into the air and reversed, and long fissures were formed, some of which remained permanently open. During the Quito earthquake of February 4th, 1797—the centre of which seems to have been the Tunguragua Volcano—Riobamba, and all towns within an area of 120 miles north and south and 60 miles east and west of the mountain were destroyed; while at Tunguragua and in the immediate vicinity Humboldt tells us that enormous rifts were formed, from which issued volumes of water and evil-smelling mud, which in places formed lakes of considerable magnitude. During the South American earthquake of February 20th, 1835, which more especially affected Chili, though it was felt as far as Mendoza, on the eastern side of the Andes, and the Island of Juan Fernandez in the west, the ground in the Island of Quiriquina was in many parts fissured in north and south lines, some of the fissures being a yard in width. Mr. Darwin, who examined the scene of this earthquake soon after it had occurred, describes the effect of the vibration on the hard primary slate which composes the foundation of the island, as shivering some of the narrow ridges as completely as if their surfaces had been blasted by gunpowder. But this effect, he thinks, must be confined to near the surface, since otherwise there would not exist a block of solid rock throughout Chili. "Nor is this improbable, as it is known that the surface of a vibrating body is affected differently from the central part. It is, perhaps, owing to this same reason that earthquakes do not cause quite such terrific havoc within deep mines as would be expected. I believe this convulsion has been more effectual in lessening the size of the island of Quiriquina than the ordinary wear and tear of the sea and weather during the course of a whole century." In Chios and Ischia, as well as in Andalusia, various places were riven in this manner; and during the Charleston earthquake of 1886 many gashes were formed, and in spots where the soil was very deep, "spring-holes" filled with water appeared. In places where the fissures run across the beds of rivers, the current will naturally tumble into, and either flow for a time underground, or, beginning by widening the gap, gradually wear away one wall of it until a lake is formed, and then possibly a waterfall like that of Niagara or the less famous one of the Zambesi will appear. This actually happened in the Mississippi valley, when the rents caused by the earthquake of 1811–12 were so enlarged by torrents as to become a regular valley or ravine; and in New Zealand there are cracks formed by modern earthquakes extending in one case sixty and in another ninety miles, while in India there is a fissure, or rather a series of fissurings, which have been traced for an even greater distance.

Levelling of Cliffs, etc.—The toppling over of chimneys and the collapse of houses, calamitous though they are to the owners and occupants, are, of course, geologically of no importance. In a few years the buildings are erected better and more substantial than before, until it requires accurate local knowledge to point to any trace of the destruction which occupied so large a space in the contemporary accounts of the shocks. But when the earthquake throws down cliffs and the pinnacles formed by the erosion of soft rocks by the weather, the result is different. Hence, when the geologist comes upon rocks delicately poised upon each other (p. 91), or upon "natural bridges," like that of Virginia, or on pinnacles like that in the Cañon of the Kentucky River (Kentucky), the Pinnacle Rock in Cumberland Gap, and the "Navaho

* "A Full Account of the late Dreadful Earthquake at Port Royal, in Jamaica," etc. (1692).

Church" Pinnacled Rocks,* he may safely infer that this particular region at least has never been shaken by any earthquakes of great violence. In this way we can presage something regarding the seismic history of regions even where written chronicles and oral traditions are silent on the subject. It is also quite within the limits of cautious observation to deduce certain facts regarding the course of earthquakes from the cracks, etc., which they have formed in the soil, in the superficial rocks, or in substantial buildings. During the Agram earthquake of November 9th, 1880, such facts were very carefully noted. In Styria, Herr Radinsky von Wies, the "Berg-Director," relates, in confirmation of a fact already on record, that while no signs of the seismic wave were noticeable in the mines of Brunn and Schönegg at a depth of 100 feet below the surface, higher up the strata were so affected that the workmen who were in the shaft at a depth of from 200 to 400 feet were in danger from the fall of the Upper Tertiary rocks above them. This, like so many other earthquakes, seems to have had a more or less rotatory motion. Near the town of Agram are—as the inscription relates—the graves of George and Peter Friedhöfen. But, after the earthquake, the foundation of the tombs was found to have been upheaved, and the gravestones violently broken across and dislocated, so that the stones, which were originally in a direct line from north to west, had been turned round from 10° to 25°. The staircase of the Cathedral Tower also was twisted in an arc on its axis, so that the deviation amounted to about two inches. Landslips are common during earthquakes. In 1885 one village in Granada was moved bodily some sixty feet in a northward direction, a deep semi-circular fissure—or "crevasse"—appearing on its former site, and at Periana a landslip on a mountain in the neighbourhood destroyed a church and 750 houses.

Changes of Level.—That the ground would be elevated or depressed during, or subsequent to, an earthquake, is only what might be inferred from what we already know regarding the action of forces evidently more or less identical with those which cause earthquake shocks. For example, the slow secular rise and fall of regions cannot but be regarded as of much the same nature as an earthquake, though the agents engaged in this elevation and depression are of a far less sudden character, and do their work after a less violent manner. Again, a volcano frequently causes a change of level in the part of the country immediately affected by it, though volcanic cones are not due to any direct elevating power of the outburst. During the eruption of Vesuvius in 1861, the shore in the vicinity of Torre del Greco was elevated over 3½ feet. After an earthquake also the ground is frequently lowered below its old level, or considerably raised above what it was before that event. The most familiar instance of this is the oft-quoted one of the Ullah Bund, a tract of country in the Delta of the Indus, which, after the convulsion of 1819, was raised throughout an area 50 miles, and in some places 16 miles broad, to a maximum height of 10 feet, while the Runn of Cutch, an area of 2,000 square miles, became at the same time an inland sea, so deep that the fort and village of Sindree sank till only the tops of the houses appeared above the water.

After the earthquake of 1855 a tract of country in New Zealand was seen to have been elevated nine feet for a distance of 90 miles. At the same time the north side of Cook's Strait — between the North and Southern Islands — was elevated five feet, while the southern shore of the same passage was depressed to a corresponding degree.

During the Calabrian earthquake of 1783 the town of Terranuova was violently disturbed. Houses were raised above their former levels: others were depressed below the line of the street; while, as not unfrequently happens during earthquakes, buildings above ground displayed "faults" in their walls—that is, one portion of the wall was shifted up, while another was lowered, as

* These are all figured in Professor Shaler's paper already quoted.

we see in the rocks on the two sides of the dislocations, which we have already learned to know under that name (p. 80). An area, 60 miles square, was depressed near Chittagong during the Bengal earthquake of 1762, so that the sea invaded the country, leaving only the highest eminence visible above the flood; and in the Basin of the Mississippi, particularly in the State of Missouri, in the earthquakes of 181–112, there was depression of the ground in many places to such an extent that the river formed lakes, where a few days before dry land—farms and forest—had been seen. About five thousand square miles were more or less lowered, and such an area of cultivated or settled ground was converted into morass that the Government was compelled to furnish hundreds of thousands of acres of new lands in higher grounds to those whose farms had become untenable. The sudden elevation of the Chilian coast after the earthquakes of 1822, 1835, and 1837, has of late, along with other phenomena of a kindred character, been questioned.* But, though not improbably some of the data so frequently cited may have been erroneously interpreted, it is idle to deny the many facts in support of the old assertions. After the earthquake of November 19th, 1882, shore shell fish, still adhering to the rocks, along with multitudes of other dead marine animals, were found at a height of from three to four feet above the sea level for a long distance along the Chilian coast. After the shocks of the 20th February, 1835, parts of the coast were raised from four to five feet, but in a few hours it sank till it was only two feet above its normal level. Admiral Fitzroy, who was on the spot at the time, found an even more remarkable state of matters on the neighbouring island of Santa Maria. "It appears," he tells us, "that the southern extremity of the

Fig. 121.—THE RUE PARTONO, MENTONE, DAMAGED BY THE RIVIERA EARTHQUAKE (1887).

* Suess: "Das antlitz der erde." Abteilung I. (1883).

island had been raised 8 feet, the middle 9, and the northern extremity upwards of 10 feet. On steep rocks, where vertical measures could be correctly taken, beds of dead mussels were found ten feet above high water mark. An extensive rocky flat lies around the northern parts of Santa Maria. Before the earthquake this flat was covered by the sea, about forty miles north of Rome, the church of Jenne, which a century ago was invisible from Subiaco, is now plainly seen over the summit of the intervening mountains. But though it is plain that there must have been a rise in that interval of the ground on which the church is built, it is, like the corresponding facts regarding the Temple of Serapis, an

Fig. 122.—THE RUE DEBRAY, NICE, DAMAGED BY THE RIVIERA EARTHQUAKE (1887).

some projecting rocks only showing themselves. Now the whole flat is exposed, and square acres of it are covered with dead shell fish, the stench arising from which is abominable."

Many facts of a like nature could be cited. The classical ones connected with the Temple of Jupiter Serapis have been already fully gone into when discussing secular rise and fall, though the elevation and depression of that monument of pagan superstition and geological history are usually regarded as due to convulsions more sudden than those to which we attributed them (p. 172). At Subiaco, open question whether the elevation has been due to a slow oscillatory movement or to a sudden start, such as we have so often seen follows or accompanies earthquakes. In Niapu, one of the Tonga Islands in the Pacific, there are frequent and violent earthquakes, during one of which—in 1861—a considerable part of the island, with a populous village, disappeared. In 1878, during a volcanic eruption, a small island was upheaved off the coast of New Britain—a case which is quite paralleled by an event of a later date (p. 167).*

* Romilly: "The Western Pacific" (1886), p. 145.

Finally, not to multiply such instances of upheaval and depression, the Moors declare that all the ports of Morocco have been changed for the worse since the Lisbon earthquake, the bars of rivers like those on the banks of which Larache, Azimoor, Salee, and Rabat are built being shoaler; and it is certain that the docks of the Roman station at "Old Tangier" are now grass-grown.

That the surface of the ground should be elevated is not remarkable when we recall certain facts. During the earthquake of 1747 the velocity of the shock—the "moto succusorio" of the Italian geologists—was so great that at Riobamba, at the foot of Chimborazo, corpses were thrown out of their graves; and at Quito, in the same region, Humboldt tells us that on the 4th of February, 1797, the "explosive movement was such as is produced by the firing of a mine, and the bodies of several of the inhabitants were thrown upon the hill of La Cullca, which rises on the other side of the Lican torrent"—or 100 feet of vertical projection, which would, according to the calculations of Mallet, give a velocity of shock equal to 80 feet per second. At Port Royal, in Jamaica, on the 7th June, 1692, the people in the market-place were tossed into the air, falling in the water of the neighbouring harbour. In the north of Jamaica, during the same catastrophe, above 1,000 acres of land sunk and thirteen people with it, and hard by the earth "gaped prodigiously," so that the planters' houses, people, and trees, with much of their plantations, were swallowed up "all in one gape," the place being soon occupied by a lake. This in its turn dried up, nothing being seen except loose sand and gravel, "without any the least mark or sign left whereby one may judge that either a tree, house, or anything else had ever stood there."* On the 28th of March, 1783, some of the attendants of Sir William Hamilton noticed the granite rocks of Calabria dancing up and down, so that the highest points seemed to be in a state of commotion; and it is well ascertained that the most violent earthquakes have been those which produced the elevation and depression of strata, besides originating cracks, dislocations, and the fissures of various forms and dimensions already described. In Lisbon the marble quay was, with all the people in it, engulfed in the Tagus, and a similar incident happened at Port Royal—the tops of the two-storeyed houses built upon the wharf becoming level with the surface of the sea. Springs become extinct, dry up, while others break forth. Water, sand, and mud are thrown out, and funnel-shaped openings appear in the ground, as at Rosarno in Calabria, and during the earthquake of the 9th November, 1880, in the Savenie district, between Resnek and Drenje, between four and five miles from the town of Agram.

* *Philosophical Transactions*, No. 209, p. 89.

Disturbance of Drainage.—It is, indeed, a natural sequence to what has been said regarding the disturbance of the strata that there should be a corresponding interference with the drainage. Accordingly, we find that almost every earthquake of any severity is followed by the drying up of old springs and the bursting forth of new ones, by the damming up of rivers and the formation of lakes, and, it is affirmed in more than one case, by the eruption of geysers long silent; while it is well established that in Iceland several of the spouting fountains now active appeared after a volcanic convulsion accompanied by an earthquake, and that several have disappeared in such close sequence to the like events, that we are justified in classing them as cause and effect. In any case, it is rare that streams are not temporarily affected by the passage of an earthquake wave. Sometimes their volume decreases, or their current altogether ceases for a time to flow, or, as we have already seen (p. 226), the water is discoloured by mud, or even rises in temperature. In 1885 many of the sulphur springs with which Granada abounds suddenly ceased flowing, and reappeared a day or two after the earthquake in a state of unusual heat. In California, during a shock in 1887, some of the hot springs stopped, and cases are on record in which the first symptoms of anything being wrong with the under-world were the wells and springs becoming dry. Lakes, we have

learned (pp. 248, 250), may occasionally be formed by the lowering of the level adjacent to a river or the sea; and when fissures are made in the bed of a lake or the level of its outlet is altered, the basin may be suddenly emptied of its contents. During the Calabrian earthquake of 1783 a new lake, the Lago del Tolfilo, was formed by the opening of a great chasm near Seminara; and, as happened at Charleston and other places, more than one pond arose as the after effects of the shocks. During the Mississippi earthquake of 1812, not only were several large lakes made, but the inhabitants relate that the ground below New Madrid "swelled so as to arrest the Mississippi in its course, and to cause a temporary reflux of its waves."

During the Arizona earthquake of 1887 the ground near Benson opened to a width of six inches, and water rose in hitherto dry places. At a distance of ten miles from Tombstone, a lake covering an acre was completely dried up in ten minutes, and in the Santa Catalina mountains the "cañons" (deep defiles) were reported to be full of water, owing to the streams being dammed up. During the Calabrian earthquake of 1783 about fifty new lakes are said to have been formed by the temporary obstruction of the rivers and brooks, and in Chili, as in other countries, the current of streams is often altered, owing to the slope of their beds being increased or diminished, while, owing to the same cause, new channels are sometimes formed, and the fertility of the country affected by this interference with the drainage, which has been changed either for the worse or the better. During the Charleston earthquake, it was reported in the contemporary accounts that from the fissures formed sulphurous fumes arose, and that, as at Lisbon (p. 246), in some places—several miles from the city—these exuded sand, white in some places, and red in others. From other openings, brackish tepid water spouted to the height of from fifteen to twenty feet, a fact which accords with the eruption of sulphur-water, sand, and mud, to the height of 30 feet during the earthquake of 1766 at Cumana, in Venezuela. In one or two spots, in addition to the sand and water, "an unfamiliar substance of an oily pasty character, like the juice from a squeezed orange," was expelled. After these ejections ceased, mounds, like the cones of mud vulcanoes, remained, so that not improbably they were really of this nature. The waters in the wells rose and fell. A railway train approaching Charleston at the moment of the shock pitched like a ship at sea; then, by a change in the direction of the wave, the cars were thrown against the opposite sides of the track. The roadway was upheaved, and the rails were bent into reverse curves.

The tales of showers of pebbles falling in different localities with intervals of three or four hours between them, have been repeated with so much circumstantiality that we are compelled to give some degree of credence to the reports. The size of the stones is said to have varied from that of a grape to that of a hen's egg, and to have fallen perpendicularly, with force enough to fracture the hard pavements upon which they struck. These stones had polished surfaces, and felt warm when handled directly after falling; but though it is quite possible, from what has been said on p. 250, that such stones were ejected into the air and fell, it does not necessarily follow that they were discharged out of the ground. Nor are the stories of flames having been seen to issue from the cracks well authenticated,* and in the same category was thought to come the tale of a volcano having broken out on the slope of the Sierra Madre Mountains, fourteen miles south-east of Bavispe, in Sonora, during the earthquake shocks which lasted for the most of May, 1887. At first this supposed volcano was affirmed to be only a mountain fire. But later intelligence affirms its existence, and that streams of lava flow down the sides of the mountain. During the Mississippi valley earthquakes of 1811–12, the inhabitants

* William of Malmesbury tells us that in 1133 an earthquake overthrew many houses in England, and that flames issued from rifts in the earth which defied all attempts to quench them. The reputed death of fishes after an earthquake must be due to the exudation of poisonous fumes into the sea, or more likely to a submarine volcanic discharge.

relate that the "earth rose in great undulations, and when these reached a certain fearful height the soil burst, and vast volumes of water, sand, and pit coal, were discharged as high as the tops of the trees."*

Dislocation of Strata.—It is equally certain, no matter how earthquakes are produced, that whenever there is either an elevation or a depression of the surface faulting must result, since a bed or series of beds could not possibly be raised or lowered without suffering dislocation of the character we have already fully described (pp. 79–82). Indeed, it is all but certain that a great many of the faults we meet with in the strata of the earth have been due to ancient earthquakes, or to the causes which produce earthquakes, be these what they may—contraction of the nucleus, sinking of the external crust to accommodate itself to the shrinking centre, explosions in certain places, or any of the other causes adduced. But apart from theory, which in this case is founded on so firm a basis as scarcely to be distinguished from absolute fact, more than one modern earthquake has furnished data amply sufficient to confirm what has been thus inferred. During a severe earthquake in New Zealand in 1855, an area of country, comprising 4,600 square miles, was permanently elevated to a maximum height of 9 feet, while the adjoining plain of Wairaraka was not raised at all, the result being a line of fault or dislocation traceable along the base of the Rimutaka Range for a distance of 90 miles.†

It is, indeed, considered by many Continental geologists—whose experience is derived from a study of Swiss and South German earthquakes—that the most destructive shocks are those which are closely connected with the formation of mountain chains. These dislocating earthquakes Hörnes describes as "tectonic,"‡ because they are caused by an alteration in the tectonic conditions of the earth's crust, that is to say, by the movements of the separate parts of it, which shift out of their places in forming mountains, according to the theory already described (pp. 187–191). The enormous pressure from different sides, and the strain of the moving rock masses, the forming of new and the enlargement of already existing cracks and fissures in the strata—in a word, any sudden disturbance in the arrangement of the beds of rock—is, of course, sufficient to produce these dislocations or tectonic earthquakes. They occur very frequently, stretch very far, and are bound to follow certain lines (the seismic lines), which might be indicated as the lines of shock. Such earthquakes might be called linear ones, in contrast to those which proceed from or are due to volcanic disturbance, or to some internal explosion, from which the tremor waves spread outward. All mountainous localities, but especially mountain ranges, and particularly the side of their range which is turned towards the sea, are more or less liable to this kind of earthquake. Such a locality is called a District of Shocks—or, as the Germans say, an "Erschütterungsgebiete," or, more shortly, a "Schüttergebiete." Some of these we have already described in considering the geographical distribution of the seismic zones. Of all these earthquake-harassed regions the slope of the Cordilleras facing the Pacific is one of the most characteristic. Scarcely a year passes without a catastrophe. Lima, the capital of Peru, has been eleven times shattered since the beginning of the sixteenth century. In Asia it is Syria, Asia Minor, Persia, the slope of the Himalayas, and the valley of the Indus, which are especially exposed. In Europe we have seen that it is the Spanish Peninsula, Italy, with the Apennines and the region of the Alps, which are chiefly disturbed. From 1850 to 1857, 1,086 earthquakes have been noted in the Alps alone; but of these only 81 were in the Eastern Alps. That so large a proportion falls to the Western Alps is, however, possibly due to the fact that the shocks have been more carefully noted in the Eastern ranges.

No part of the Alps is quite free from them. But the most intense disturbances are in the

* Lyell: "Principles" (Ed. 1834). Vol II., p. 190.

† Roberts in Lyell's "Principles" (10th Ed.), Vol. II., p. 86.

‡ *Jahrbuch Geol. Reichsanst.*, 1878, p. 448.

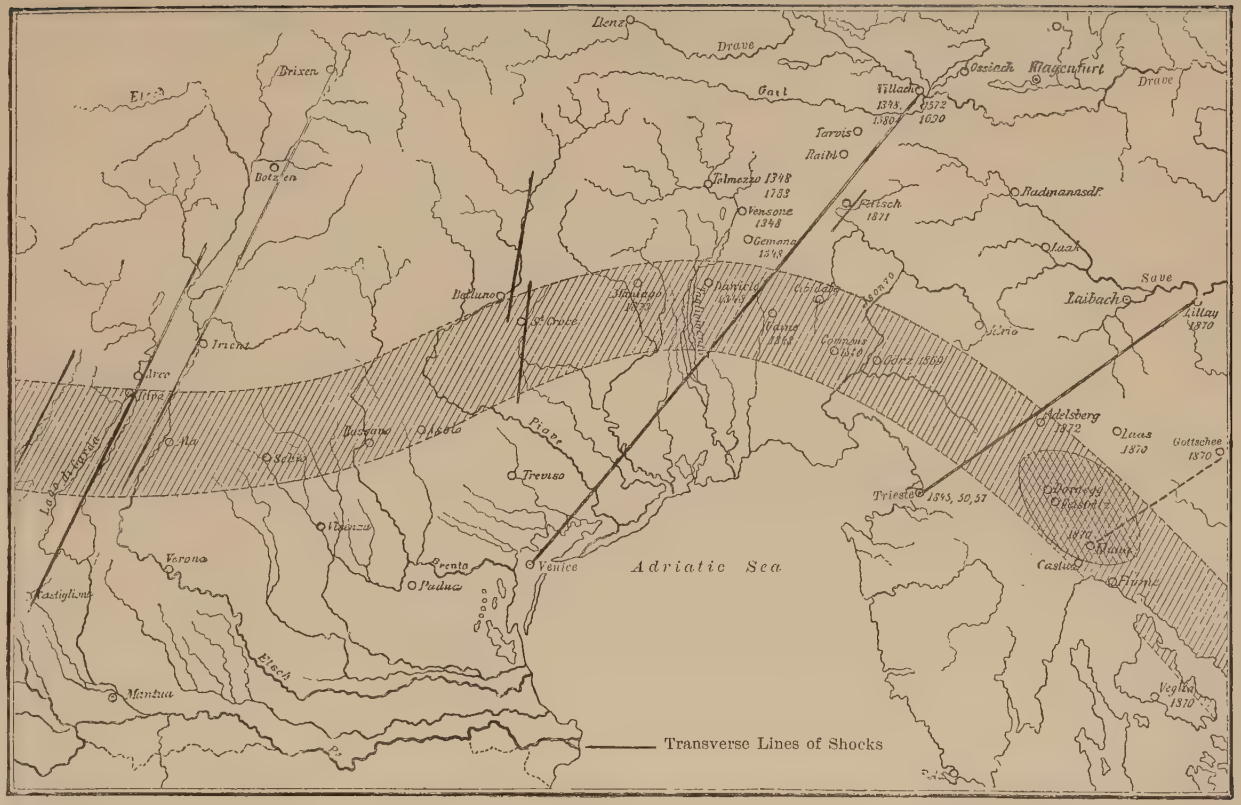


Fig. 123.—THE EARTHQUAKE ZONE OF THE SOUTHERN ALPS, WITH THE RANGE OF THE EARTHQUAKE OF KLANA (1870). (*After R. Hörnes.*)

southern part of the Cadoric, Carnic, and Dinaric Alps, bordering the Adriatic. This district is generally called the earthquake zone of the Southern and South-eastern Alps. The latest researches of the Austrian geologists (Suess, Stur, Bittner, Höfer, and Hörnes) upon the seismology of the Alps and Apennines tend to show that the lines of shock in these earthquakes are indicated by the lines of disturbance in the formation of the mountain ranges, as these coincide, in part at least, with the earthquakes across the ranges, and partly with those in a longitudinal direction.*. We find a district of frequent and severe disturbances along the inside of the Eastern Alps on the north-east coast of the Adriatic. To this district belong the frequent earthquakes of Northern Italy, and the edge of the Southern Alps towards the Lombardo-Venetian Plain, and also the earthquakes in the Plateau of the Karst. These disturbances can be recognised as extending from the Lago di Garda over the region in which are situated Ala, Schio, Bassano, Asolo, Belluno, and Maniago to Tagliamento. At Udine, which in 1384 was the scene of one of the greatest earthquakes known to history, the line of disturbance turns towards the south-east. Now come the earthquake regions of Gormons, Görz, Gradisca, Adelsberg, and then that of Klana in the coast country, which in 1870 was disturbed by a series of shocks; and at last we reach that of Fiume. After this we can follow the region of disturbances into the Istrio-Dalmatian Karst, as shown on the annexed map (Fig. 123).

Hörnes, quite correctly, connects the disturbances of the region with the peripheric line of fracture ("bruch linien") on the inner side of the Alps, and with the movements of parts of the mountains of the inner region. This he illustrates by a profile of the Italian plain above Belluno to the neighbourhood of Agordo (Fig. 124).

Besides these peripheral or circum-montane lines of disturbance, there are numerous radial or transverse lines of shock coinciding with similar lines of dislocation. These lines must be regarded as partly forming the borders of masses just in the act of sinking, and partly as divisions between two regions which are moving horizontally away from each other. The Belluno earthquake of June 29th, 1873, which did so much damage to the town and neighbourhood, afforded several good examples of this kind of disturbance. It was very carefully studied by Vom Rath, Bittner, and Hörnes, and it would appear from a diagram prepared by the latter geologist (Fig. 125) that the line of shock coincides with the transverse dislocation of St. Croce, which latter is at the same time plainly the division between two mountain masses moving horizontally from each other.

As transverse lines of shock there may also be pointed out the line running from Trient, Botzen, Brixen; that from Venice, Raibl, Villach (the course of the earthquake of 1384†); that from Trieste, Laibach, Cilli, and others (Fig. 123), from all of which the shock has often been felt far into the recesses of the Alps, as well as in the outlying branches.

These data are of course intended to illustrate only one theory of the cause of earthquakes, or the way in which one particular class of them is caused, namely, by the sinking and crushing of strata. Suess will, however, maintain that in other regions of the world besides that which he has studied, the connection of the earth with these tectonic lines can be recognised. The terrible Calabrian catastrophe of 1783 is a case in point. It moved along the inner fault line of Aspromonte, which coincides with the periphery of the Calabrian mountains. In studying the earthquakes of Central Germany, Von Seebach came to the conclusion that the seat of these was most likely a fault, which ran nearly from north-north-west to south-south-east but had only a very slight horizontal expanse, and in the east-north-east penetrated far into the crust of the earth. These "dislocation earthquakes," therefore, mainly, or at least very

* *Querbeben* and *Längsbeben*, as they call them.

† This was on the 25th of January. In addition to other damage, two market towns and seventeen villages were overwhelmed by the fall of part of the Dobratsch, or Villacher Alp.

frequently, occur in regions in which great change of height, and especially upheavals, have been observed. The very fact of these moun-

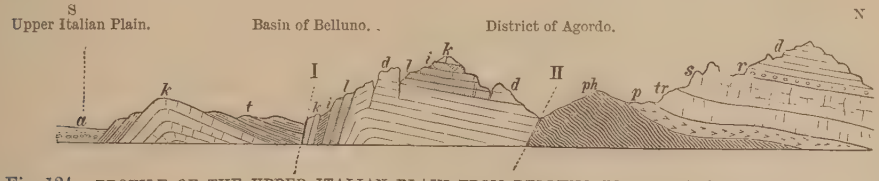


Fig. 124.—PROFILE OF THE UPPER ITALIAN PLAIN FROM BELLUNO TO THE NEIGHBOURHOOD OF AGORDO.
(*After R Hörnes.*)

a, Glacial and Post-glacial deposits; *t*, Tertiaries; *k*, Cretaceous beds; *i*, Jurassic; *l*, Lias; *d*, Dachstein limestone (Rhætian formation); *r*, Raibl schists; *s*, Dolomite; *tr*, Lower Lias; *p*, Permian; *ph*, Phyllite; I and II, Faults in the strata.

tains existing proves that earthquakes must have existed from the beginning of the world. It is possible, slight though the sinking which causes the greatest earthquake of this kind

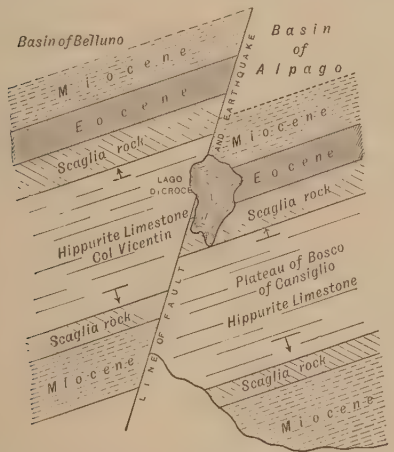


Fig. 125.—FAULT AND LINE OF THE EARTHQUAKE OF ST. CROCE. (*After R. Hörnes.*)

is, that the very mountain-tops—measured with even greater accuracy than it is possible to do—would have been found altered after a shock. Only very young regions — with their beds of rock still undisturbed, and without mountains—or the regions of very old mountains, are free from earthquakes. From the North German lowland, over European Russia and Siberia to the Baikal, the earth, it was a dictum of the acute Peschel, "rests in perfect peace." Central Asia has, however, been often shaken, and no later than June, 1887, Viernoe—a town of three thousand houses, two thousand of them built of stone—and many villages were severely damaged or destroyed by one which was felt over a radius of 670 miles. Many lives were lost, both by the falling of the buildings and by tumbling of masses of rocks in the mountains. Herds of cattle belonging to the Kirghiz were destroyed. Nine miles from Viernoe, on the Aksa, the earth cracks were enormous, and, according to the official report, "produced high fountains of water."

In Tashkent there are frequent and sometimes severe shocks, and the mosque over the tomb of Hazret Hodja Akhmed Yasavi is in many places cracked. In Central Asia, however, it may be added that the earthquakes are, for the most part, in the mountainous districts, and that they occur most frequently in March, or about the time of the vernal equinox. As this is the beginning of the new year, it has become an article of belief among many of the natives that the year cannot really begin until an earthquake has been felt, and it is said that some Sarts even stick a knife slightly into the ground, and do not celebrate the new year's feast until the knife has been stricken down.*

To sum up, it may be concluded from what has been said that, though the shock which causes an "earthquake" may in some instances be an explosion, in others it is this crushing in and sinking down of strata, while local ones are occasionally caused by volcanic movements, or by the falling in of caverns.

* Schuyler: "Turkistan," Vol. I., p. 329.

CHAPTER XIV.

Earthquakes: Their Folk-Lore and their Prophets.

Popular Belief in Earthquakes being Influenced or Precipitated by the Weather—What Ground there is for this Idea—Atmospheric Pressure—Knott's and Darwin's Observations—Influence on National Character—Folk-Lore of Earthquakes—Earthquake Prophets—The Unscientific and the Astrological—The Quasi-Scientific Seers—Delauney—Falb—Innate Unsoundness of their Methods, and consequent Uselessness of Results—Equal Impossibility of Predicting Volcanic Outbursts—Possibility of Minimising Effects of Earthquakes—Professor Milne's Results.

If the reader has ever glanced over the description of an earthquake shock, he cannot fail to have noticed the care with which the newspaper reporter mentions the state of the weather at and before the date of the event: whether it was still and sultry—which is generally the case,—or what was the particular state of the barometer and thermometer at the hour when the tremors occurred. This is a proof of how firmly popular belief holds to the notion that earthquakes are in some way influenced by the weather. This notion is, however, held by theorists more scientific than the excited people who fill the newspapers with their vain imaginings regarding the causes which led to the catastrophe. There are, indeed, writers as worthy of respect as Mr. Proctor who hold that "the changes of atmosphere and oceanic pressure are potent factors in the production of earthquakes, and are probably, in the greater number of cases, their direct occasion;" while, on the other hand, the observations of numerous students in Europe and America go far to show that the state of the weather has no more to do with a shock in the earth's crust than a "fall in Eries" or the price of consols the day before. Between these extremes there is room for every variety of opinion to be held.

Earthquakes and the Seasons.—M. Perrey, by comparing all the records of earthquakes which were accessible to him, tried to show that they were most frequent at the time of full and change of moon, "more when the moon is nearest to the earth and more when she is on the meridian than at the times and seasons when she is not in those positions relatively to the earth." The inference drawn from this is, that the same cause which produces tides acts on the solid crust of the earth, and therefore induces a strain on the rocks composing it. But, unfortunately for the soundness of these views and the deduction from them, neither they nor the ideas of Schmidt*—that shocks occur most frequently in January, when the earth is nearest the sun, and least frequently in July, when it is farthest from that luminary—are quite borne out by observations in other parts of the world. In Japan, for example, the seasons of maxima and minima are entirely different, and in California the autumn months are believed to be the ones most often disturbed by these disagreeable visitors, while the summer months are those which are least seldom disturbed; though in California, as in Europe, January has always proved a month of maximum frequency. In Japan also, though the periods of maxima and minima do not coincide with those of Europe, Dr. Knott admits that earthquakes are in those islands relatively more frequent in winter than in summer, and connects this with the fact that during winter the average barometric gradient across Japan is much steeper than in summer, which, coupled with the piling up of snow in the northern regions, may possibly "give rise to long-continued stresses, tending to produce movements of the earth's crust." This suggestion has some support in known facts.

* "Studen über Erdbeben" (1879), pp. 18-20.

NORTH-
AMERICA
EUROPE
GERMANY
FRANCE
SPAIN
PORTUGAL
ITALY
ALGERIA
MOROCCO
TRIPOLI
SENEGAMBIA
LIBERIA
GUINEA
WEST
INDIES
CARIBBEAN
SEA
VENEZUELA
GUIANA
COLUMBIA
SOUTH-
AMERICA
BRAZIL
ARGENTINE REP.
URUGUAY
PATAGONIA
Dolphin Bank
Challenger Bank
Bottom Temperature
Bottom-Temperature 1·7
Bottom-Temperature 1·8 - 2·2
Bottom-Temperature 1·8
Bottom Temperature under 1°
Basin
Bottom-Temperature
-0·4 to -0·6
of the Antarctic
Tonque
Azores
Madeira
Canary I.
Cape Verde
Bermuda Is
Bahama Is
Trinidad
Equator
St Paul I.
Fernando Noronha
Ascension
St Helena
Tristan d'Acunha
Falklands
South Georgia
Sandwich Land
Cape Town
Cape of Good Hope
Bay of Biscay
C. Finisterre
Str of Gibraltar
Gulf of Guinea
Bay of Fundy
C. Cod
C. Breton
Sable I.
Halifax
New York
Jamaica
Porto Rico
St Thomas
Pernambuco
Bahia
Abrolhos I
Trinidad I.
Rio de la Plata
Cape Horn
Str of Magellan
Tierra del Fuego
Corsica
Sardinia
Balearic Islands
Malta
Sicily
Congo
Tenerife
Abaco
Bahama
Jamaica
Porto Rico
St Thomas
Equator
St Paul I.
St Roque
Fernando Noronha
Pernambuco
Bahia
Abrolhos I
Trinidad I.
Rio de la Plata
Cape Horn
Tristan d'Acunha
Cape Town
Cape of Good Hope
Congo
Tenerife
Canary I.
Madeira
Azores
Bermuda Is
Bahama Is
Trinidad
Falklands
South Georgia
Sandwich Land
Corsica
Sardinia
Balearic Islands
Malta
Sicily

For instance, the barometer ranges through fully two inches, and a pool of mercury two inches deep and a square foot in area weighs 145 lbs. Hence, as Professor Darwin has shown, when the barometer is very high, every square foot of the earth's surface supports about 140 lbs. more than when it is low; and 140 lbs. to the square foot is 1,800,000 tons to the square mile, so that it is likely that we are—if his calculations regarding the probable elasticity of rocks are correct—at least three or four inches nearer the earth's centre when the barometer is very high than when it is very low.

On May 3rd and 4th, 1887, there were very sudden changes of barometric pressure in Berlin, which could only be accounted for by meteorological phenomena. This fact has been noticed as coincident with the Sonora earthquake (pp. 231, 252), and, though possibly the one instance is more appropriate than the other, it may be recollected that the Krakatau eruption was also accompanied by sudden changes of the atmospheric pressure in Europe.*

So far it is quite possible to admit that in some way the weight of the atmosphere, or the attraction of the other planets, may influence the earth's crust so as to produce, or intensify, earthquakes, though for the present it is safer not to reckon too much on this theory. There is, however, no ground at all for holding that the temperature of the air, the state of the wind, or any similar atmospheric condition, can in the remotest way be concerned in the phenomena under discussion.

Fig. 126.—THE GUARD-HOUSE, CHARLESTON, SHATTERED IN THE SOUTH CAROLINA EARTHQUAKE OF 1886.

(From a Photograph.)

Folk-lore.—The suddenness with which an

* Von Bezold, in *Naturwissenschaftliche Rundschau*, May 21st, 1887.

earthquake spreads desolation over wide regions, as well as the mystery with which it is attended, has from the earliest periods of the world's history invested it with a peculiar horror. The mythology of almost every nation has been busy with devising tales to account for these movements of the subterranean world. In Mongolia they are attributed to the heavings of a huge frog in the interior of the earth; in China a great dragon is blamed; in India there is a world-bearing elephant invoked to explain them; in Celebes a hog takes the place of the elephant; and among some of the South American tribes a tortoise is credited with producing the tremors. A world-supporting bull is in other regions pressed into service. In Siberia earthquakes are set down to the trampling of mammoths that live underground, and in Kamtchatka they are regarded as the scratchings of certain flea-pestered dogs, which attend the god Tuil on his walks. On the western shores of Vancouver Island—a part of America in which mild earthquakes are frequent*—the Indians regard earthquakes with peculiar dread. During one which some friends of the writer experienced, the savages who belonged to the expedition set up a fearful yell, which they continued until all the white men of the party had come out of their tent. They then begged them to fire their guns in order to frighten away the spirit of evil, who, according to their mythology, comes upon the earth, at this particular time, with all the Indians who have ever died, to slay the living for the evil they have committed. The rumbling noise they attribute to the tramp of the imaginary host. And here I may add that the close connection which the aborigines trace between the earthquakes of this region and the eruption of the volcanoes in the Cascade Range, is borne out by certain facts within my own knowledge. After a shock felt in Victoria, Vancouver Island, on October 30th, 1864, a change was observed in the form of the old crater of Mount Baker, distant about ninety miles in an air line. It was generally believed that about 1,000 feet of the summit fell in at the time, though no eruption was visible. In 1858 there was an earthquake in the vicinity of Victoria, with smoke and flames issuing simultaneously from Mount Baker. During the earthquake of the 22nd of October, 1865, which shook California, Mount Hood, in Oregon, emitted smoke and other fumes.

The Japanese, also, have their seismic mythology. One of their oldest legends ascribes them to the movements of a creature called Jishin-mushni—"the earthquake insect"—having an oblong, scaly body, ten legs, feet like spiders', and the head of a dragon. On this, however, at a place called Kashima, rests the Kaname rock, with which it is the duty of the Kami, or deity of the district, to keep the creature as quiet as possible. Hence the old earthquake couplet:—

> "No monster can move the Kaname rock,
> Though he tug at it never so hard,
> For over it stands, resisting the shock,
> The Kashima-Kami on guard."

A legend of later origin makes the Jishin-mushni a monstrous cat-fish.† These, and a score of similar myths, more or less unrelated to anything in the phenomena themselves, have invested earthquakes with a horror even greater than their actual calamity is capable of inspiring. Add to this, the sickness and nausea which almost invariably accompany them, and the illness which frequently follows a severe shock—possibly from the fumes emitted through the cracks,‡ though unquestionably also from the shock which the nervous system has sustained—and one can easily conceive the influence which these convulsions of the globe exercise over the ignorant, and even the cultured. Buckle's theory regarding the relation-

* They extend all along the coast. I have experienced a slight one in the Queen Charlotte Islands off the northern frontier of British Columbia. In the southern island of the group the Indians told us of a hot spring being in existence, though Mallet is quite wrong in placing a volcano on these islands, as he has done in his map illustrative of the distribution of volcanoes and earthquakes over the globe.

† "Earthquake Researches in Japan," The *Times*, Jan. 7th, 1887.

‡ In Iceland and other regions it is noticed that there is much illness after a severe volcanic eruption, no doubt from the same cause.

ship of Latin superstition to Peninsular and Italian earthquakes has already been noticed (p. 19). But it is equally open to discussion whether the listlessness, the recklessness, the fatalism of the people of earthquake-riven lands are not just as much encouraged by the dread that all foresight is in vain, that it is idle providing for the morrow when a tremor may destroy in a moment the labours of a generation. This continual, ever-present, never-ending dread of the earthquake, has coloured the lives of the races subject to it, and, it may be, has so imprinted itself on the minds of primitive man as to generate many of those "Nature myths" over which so much ink has been shed. It must also have tinged his poetry and his religion, and imprinted itself on his art and his mode of life. How far the classic faith of the Greeks and Romans was influenced by it, Vulcan, Pluto, and Enceladus, are in proof, but it may also be found that the bizarre art of Japan owes as much to the earthquake legends of her people, as the happy-go-lucky disposition of the Neapolitans does to the fact that with the sight of Vesuvius ever before their eyes, and the legends of buried cities never absent from their memories, they find it hard to spend thoughts over the morrow, since providence availed not the citizens of Herculaneum and Pompeii.

Prophecies.—But of all the outcomes of the superstition engendered by earthquakes, the eagerness for prophesying their arrival is the most remarkable. That men would like to be able to forecast such calamities is only natural. But how any one can imagine that in the present state of our knowledge this is possible, is not so easily to be understood or accounted for. Yet it seldom happens, after a more than usually violent shock, that some one does not claim the distinction of having foretold it, or that some more or less vague allusion to the coming event is not disinterred from the pages of an astrological almanac; though in no case can these soothsayers explain how this, among their many other prophecies, became true, when ninety-nine of a hundred similar attempts to peer into futurity proved entirely futile. When earthquakes were regarded as the means adopted by Providence for punishing a sinful world, there was never any great difficulty in playing the prophet; for the world is always ready enough for the divine rod,* and if one is only patient the rod is sure to arrive. For instance, the earthquake which in 1682 almost entirely demolished Lima, was said to have been foretold by a friar of the Order of La Merced, who several days before ran along the streets, like another Jonah, crying, "Repent! Repent! for the end of all things is at hand." Again, that of 1746 was affirmed—after it was over—to have been prophesied by "our Mother Teresa" of Jesus, in the convent of the Barefooted Sisters of St. Joseph; and one which began in Canada on the 5th of February, 1663, and continued till July 12th of the same year, "occasioning incredible alterations on the surface of the land for above 400 leagues," seemed—if we are to credit certain hints in the memoirs of an Ursuline nun of New France, published in 1677—to have been, months before it happened, in the knowledge of certain good people, who, however, do not appear—like Parthenios, the monk of Chios, who loudly proclaimed an earthquake on a definite day in 1881—to have benefited themselves by their exclusive information.

At the same time, while not for a moment admitting that these amateur "haruspices" had any basis for the prophetic superstructures which they reared,† it would be unfair to affirm that they were attempting to deceive. No doubt they imagined—as they had imagined many times before—that "something was going to happen," and, not being very particular as to dates, concluded, when a catastrophe did come, that it was something more than a mere coincidence. In Peru and

* A New England newspaper of 1727 mentions that "a considerable town in this province has been so awakened by the awful Providence in the earthquake, that the women have generally laid aside their hoop-petticoats."

† "A True and Particular Relation of the Dreadful Earthquake which happened at Lima, the capital of Peru, and the neighbouring Port of Callao, on the 28th of October, 1746," etc., etc. (1768), contains much useful information collected on the spot, with some speculations more entertaining to the student of psychology than of physical geography.

other regions earthquakes are so frequent that it is always safe to prophesy their advent, for if it does not come when it is foretold, one is sure to come some time, and the world always remembers the lucky guesses, and forgets the endless failures. Indeed, most people who have lived in a seismic region, even when scoffing at all pretensions of this nature, admit that often before a shock they have had forebodings, in spite of themselves, that a calamity was at hand. A sensation of lassitude and depression is the most common feeling experienced, and even Mr. Milne—who is one of the last men to encourage any absurdity in the shape of "prophecies"—admits that he has on several occasions been so impressed by these premonitory symptoms in his own person, as to have his instruments in readiness to observe the shock. This, however, he attributes to "nervous expectancy," due to the knowledge that, as there had been no earthquake for several weeks, one was due at any moment. In Caracas, however, dogs, cats, and jerboas are affirmed to become restless prior to an earthquake, and before the first shock in the Riviera in February, 1887, a groom observed the strange uneasiness of his horses, which laid their ears back and refused to be comforted. In Chili immense flocks of sea-birds have been observed to fly inland just before a severe shock, and in 1835, all the dogs escaped from the city of Talcahuano in anticipation of the earthquake of that date.* These may have been coincidences. Birds fly inland and cats are uneasy when there are no earthquakes to justify their movements, though, on the other hand, the lower animals are singularly sensitive to any change of weather, to pressure of the air, and may even be conscious of subterranean movements which do not come within human ken, or are even not detectable by the most delicate instruments.

The success of the earthquake prophet is generally out of all proportion to his merits. Especially after a great shock the panic-stricken population are always ready to listen to any quack, no matter how silly or how knavish. In 1750, after the London tremors in the spring of that year, when, according to Horace Walpole, "the earth had a shivering fit," pills were sold "as good against an earthquake," and a crazy lifeguardsman predicted a third and more fatal shock with such influence, that, as the time fixed for the catastrophe drew nigh, the roads leading out of London were blocked with the carriages of panic-stricken people clearing out of town. Many of the nobility sat in their coaches all night in Hyde Park. "Earthquake gowns"—warm garments to wear while sitting out of doors—were greatly in request, and certain aristocratic ladies went ten miles out of London on the fatal night, returning in the morning somewhat disappointed that the 5th of April had passed without the soldier's prophecy having been fulfilled.

Seers of this order are never wanting, and after the Riviera earthquake some people made clamorous pretensions to public esteem from having "foretold" what they could not possibly have had any knowledge of and never tried to guard against. But the quasi-scientific prophets are barely preferable. The theorists who connect almost every human misfortune, from an Indian famine to the potato disease, with the greater or less spottedness of the sun, have not failed to point out that some relation might be traced between the convulsions under the soil and those dark spaces in the orb of day, though, it is perhaps needless to say, in every case altogether without success.

M. Delauney, finding that in Perrey's catalogue—a very incomplete one at best—there were certain terms of years marked by a comparative absence of earthquakes, tried to find an explanation for this real or fancied periodicity in the movements of other celestial bodies. This, he believed, he had discovered in the fact that the epochs of maximum seismic energy coincided with certain phases of Jupiter and Saturn, and that these periods of earthquake frequency are identical with the passage of the Earth and

* *Murray's Magazine*, June, 1887, pp. 813—822, where Mr. Westwood Oliver discusses in a most satisfactory manner the various earthquake prophecies which come within the range of reason.

the planets in question through the meteoric streams which are known as the Perseids and Leonids (August and November showers). Hence, as the Earth passes through these meteor swarms, it is troubled with earthquakes, and when either of the planets mentioned undergoes the same experience, it also is perturbed in a like manner; though why this should affect the Earth we have still to learn, even admitting that it caused tremors in Jupiter and Saturn. If the shock of these planets encountering the meteor ring is so great as to influence the crust of our earth at a distance of millions of miles, how is it that when the Earth itself passes through the same ring of shooting stars (as it does in August) the effect is not infinitely greater, instead of being utterly undetectable? Moreover, the data upon which the theory is formulated relate to only a small portion of the globe, while, if there is anything in it, its application would be world-wide. Altogether, M. Delauney's theory is utterly untenable, and would probably never have received anything like the attention which it has met with had it not been supposed that his predictions of memorable seismic activity during the years 1883 and 1886 were remarkably fulfilled; though even then this could have been no more than a guess, since others put forward with equal confidence proved quite futile.

Fig. 127.—STREET HOUSES IN CHARLESTON DAMAGED IN THE SOUTH CAROLINA EARTHQUAKE OF 1886.

(*From a Photograph.*)

Dr. Rudolf Falb, of Vienna, is another earthquake prophet, held in such esteem that a lady of Mr. Oliver's acquaintance dismantled

her drawing-room so as to be prepared for an English earthquake which he had predicted. He "foretold" the Belluno earthquake of June 28th, 1873, and, though his failures have been numerous and notorious, he once more rose into esteem by prophesying the Riviera disaster, though, it may be added, his vaticinations as to shocks which were to follow this calamity, founded on a perfect parity of reasoning with the former one, were conspicuously unsuccessful. Falb's theory is that the interior of the earth being liquid, the attraction of the sun and moon, which, as is known, causes tides in the ocean, compels this liquid mass to ebb and flow up the rifts which he supposes exist in the interior surface of the covering crust, "just like the sea in our bays and estuaries. When the hot matter enters the solid and comparatively cold channels in the earth's crust it is rapidly cooled, and explosions of gas and subterranean volcanic disturbances result. The violence of these phenomena depends on the height of the internal tides, and as that, in its turn, depends upon the relative position and distance at any time of the sun and moon, the whole thing may be reduced to calculation, and the earthquakes, which are the external manifestation of the internal phenomena, be foretold with the exactitude of an eclipse."

This hypothesis, it will be seen, is based on a very unstable foundation, for it takes for granted ascertained facts what are only assumptions by no means universally accepted. For instance, though the probabilities are in favour of the earth having a molten interior, this is not in any degree proved, and, as we have seen (p. 84), is by many physicists stoutly contested. As for the fissures in the crust into which the fluid matter ebbs and flows, these are mere inventions. Nothing in the history of the earth justifies Dr. Falb in evolving them from "the depths of his inner consciousness." Moreover, as Mr. Oliver very properly points out, if the supposed molten matter was constantly flowing into and hardening in these supposed fissures, they would soon fill up and disappear. Thus, unless new ones were constantly in process of formation, the phenomena which this best-reputed of the earthquake prophets regards as essential to the success of his vaticinations would not exist. And, above all, though the pull of the sun and moon may cause a certain strain on the earth's crust or substance, it is entirely unproved that anything like tides is formed; and, if these tides did exist, then they must be regular like the oceanic tides, and, of course, the earthquake phenomena would share in this steady periodicity—a circumstance which, it is perhaps unnecessary to remark, does not hold true regarding them. Nor does the often-repeated argument that, though the theories of MM. Delauney and Falb may be scientifically unsound, their results have been remarkably correct, help them much. Earthquakes are so frequent in many parts of the earth—and, taking the world at large, so continuous—that it is no merit to be able to foretell their occurrence in any one year. The only claim to distinction arises from the ability of the seer to say that those of any particular year will be more or less severe, or that one may be expected to occur at some fixed date. All that M. Delauney affects to have been able to accomplish was to foretell those of 1883 and 1886. But even this shadowy lustre is dulled by the fact that, while he predicted 1883 to be an ordinary year, he confidently declared that 1886 would be one of great intensity as regards its seismic commotion, while the very reverse turned out to be the case. Falb's theory is more sound — taking prophetic soundness as the standard—though it also must, from the circumstances stated, be largely helped out by one or two happy coincidences in a field where such coincidences are likely to be frequent. Tidal strain as *the* cause of earthquakes is out of the question. "As the facts stand," and I quote the words of Professor Milne because they express in a single sentence the only conclusions tenable, "it appears that the maximum pulls exerted by the moon and the sun are only sufficient to cause a slight preponderance in the number of earthquakes felt at particular seasons, and, therefore, that

these pulls only result in earthquakes when the disturbing effect has been exerted on an area which, by volcanic evisceration, the pressure of included gases, and other causes, is on the verge of yielding." But what portions of the earth, if any, are in this critical condition, no man can tell; but, as earthquakes tend to predominate at the period when the pull of the sun and the moon is greatest, it may happen that in a few instances Dr. Falb's warnings have been justified, though the number which come into that category bears no proportion to those which have not yielded any fruit.

Earthquake warnings are therefore not possible in the present state of our knowledge. At best, they are only fortunate guesses and accidental coincidences, and the most pretentiously scientific of the order are not better based than the weird warnings of Zadkiel's Almanac, or of the professional astrologer whom the city of Lima used to maintain, and who—after the event—showed to the satisfaction of himself, if not of his patrons, that the great catastrophe of October 28th, 1746, was due at the time it happened. For "the sun was in five degrees ten minutes of Scorpio, and the moon in not much less of Taurus: so that these planets wanted very little of being in opposition." The appearance of the aurora, a hankering after the electrical theory (p. 236), planetary conjunctions—the favourite whim of the seers, who considered the stars as controllers of the destinies of man—and a host of similar doctrines, with the imaginary "laws" deduced from them, are all alike unworthy of serious thought. A time may come when we may predict the weather underground with not much more error than that with which the weather overhead is forecast; though even when this period arrives it will be no more possible to say months or years in advance whether an earthquake is to occur, than it is to prophesy at a longer interval than twenty-four hours whether the sky is to be overcast, the barometer low, or the thermometer high.

It has even been attempted to foretell volcanic eruptions. This is, if possible, an idler task than predicting earthquakes. We know, doubtless, that in many instances a volcanic outburst finds its way to the surface along some line of fissure or deep depression in the earth's crust, though in many other cases the contrary is true; and in Utah the ancient volcanoes of that region seem, according to Dutton, to occur very rarely at the base of a cliff, and, when near faults, on the lifted rather than on the depressed side of the shifted strata. This, to some extent, so far as the avoidance of valleys is concerned, holds good of the volcanic region of the Rhine and Moselle.

Stromboli, we have seen, is almost a barometer to the seafaring men of the Eastern Mediterranean, and Etna and Vesuvius have been more frequently in eruption during spring and winter than at any other season. Finally, Hawaiian residents are inclined to think that great eruptions of the volcanoes with the accompanying earthquakes of these islands are sometimes preceded by wet weather. But this supposed fact has never been confirmed. Nor is there any ground for believing that few sun spots and diminished magnetic disturbances, or the occurrence of the August meteors, have the slightest connection with the greater or less degree of volcanic intensity.

Precautions against Earthquakes.—But if we cannot guard against earthquakes by knowing the hour and the manner in which they come, we can at least so put our houses in order that when the inevitable overtakes us the mischief may be reduced to a minimum. The building site should be selected with some regard to what experience relates respecting its greater or less immunity from vibrations, since we know that within the limits of a single town one place is often more shaken than another (p. 239). If in any particular region the earthquake shock originates from a single important centre—as very generally is the case—then the site should, as far as possible, be selected on the limits of the range of the usual vibrations, for, as Professor Darwin tells us, just as a high wall, a hill, or a railway cutting often cuts off sounds by forming a "sound-shadow," so a ravine or some arrangement of the geological formation may afford an "earthquake

shadow" for particular spots. Mr. Milne thinks it best to avoid a loose soil, such as gravel, resting on harder strata, and the edge of a bluff, or the foot of similar eminences. In building, the same admirable investigator considers that the openings in a wall ought to be

Fig. 128.—"NEWS AND COURIER" OFFICE, CHARLESTON, DAMAGED IN THE SOUTH CAROLINA EARTHQUAKE OF 1886. (*From a Photograph.*)

so arranged that for horizontal stresses the wall should be of equal strength for all sections at right angles; that lintels should be placed over flat arches; that heavy-topped roofs and chimneys should be avoided; that arches should curve in their abutments; and that roofs should have a low pitch, and their tiles, especially on their edges, be firmly secured. Well-built houses are less liable to destruction than flimsy ones. During the Riviera shocks in 1887 the buildings which suffered most were old ones, in bad repair, or still marked by the effect of previous earthquakes. The prehistoric races of Central America and Yucatan seemed to have clearly understood the wisdom of rearing their houses in such a manner that they might bear the shock of an earthquake with the minimum of risk. In Uxmal or Palenque, for example, the buildings are enormously massive at the base, sloping gradually from the ground to the eaves on the outside, giving to each structure the appearance of an abbreviated pyramid. The best proof of the power of such a wall to resist the effects of an earth vibration is the fact that many of these structures are still in perfect preservation, though they have stood in the middle of an earthquake country for unknown

centuries (Fig. 129). High ground enjoys, in Japan at least, greater freedom from the effects of earthquakes than low marshy places in the vicinity. Sometimes shocks are so shallow that instruments placed at the bottom of a pit ten feet deep are almost unaffected by the vibration (p. 247).

this subject that the old Romans and Greeks found that caverns, wells, and quarries protected buildings from disturbances of the earth; that in Rome wells were dug round the Capitol for this purpose; that, according to Humboldt, the same was done at San Domingo; and that Quito is said to receive

Fig. 129.—VIEW OF PALENQUE, MEXICO, SHOWING THE PYRAMIDAL STRUCTURES.

As a whole, Mr. Milne's observations demonstrate that, after experiments at any proposed site, it ought to be possible to arrive at tolerably safe conclusions whether buildings having isolated foundation-walls or piers, carried up from ascertained depths, as in the case of astronomical instrument piers, may not be rendered safe from earthquake shocks of ordinary intensity, or at least from such of them as have their origin at distances sufficient to render the vibrations practically horizontal. It is interesting to note in connection with

protection from the numerous cañons or defiles in its neighbourhood. In another series of experiments, Mr. Milne sought the best means of employing the inertia of a building to neutralise earthquake effects. With this object he set to work on a principle first applied by the late Mr. David Stevenson, in connection with the lighthouses of Japan. Mr. Milne's method was to raise a one-storeyed wooden house on pier-supported beams, introducing at the points of support round shot carried between iron plates shaped and affixed

for the purpose. After many trials, beginning with ten-inch cannon balls, which, as well as several of smaller sizes, were found to be too free in their action, the best result was obtained with a handful of cast-iron shot of a quarter of an inch in diameter, working between flat iron plates at each pier-head. These, while affording due stability to the house during high winds or internal movements, enormously reduced the motion caused by shocks; and the method has proved itself to be undoubtedly well suited to bungalows or other light structures in countries liable to what Shakespeare describes as the earth "with a kind of colic pinched and vexed."*

CHAPTER XV.

Denudation: Rain and Springs; Their Geological Action.

The Wearing Down Agencies at Work—Their Mutual Relations—Springs and the Way in which they are Formed—Amount of Water Discharged—Various Forms—Intermittent Springs—Submarine Springs—Artesian Wells—Description of the Most Remarkable—Chemical Action of Rain and Springs—Caverns, Pipes, Swallow Holes, etc.—Mechanical Action—Earth Pillars—Mauvaises Terres—Landslips—Falkland "Stone Rivers"—"Devils' Castles" and Similar Results of Weathering.

Hitherto, in tracing the story of the Earth, we have mainly considered the forces by which it is violently tossed about. But if the volcano and the earthquake, or even the slow secular rise, had all their own way, the world would be a world of ruins, of *disjecta membra*, of jagged rocks, and black lava fields, of deserts instead of fertile valleys and rich corn lands, and forests stretching as far as the eye can see. However, no sooner does the volcano vomit forth the entrails of the earth, or the earthquake rive its skin asunder, than another force, which does its work through many agents, sets to work and clears away the *débris*, smooths down the rough places, covers with a kindly soil the bare lava, and, in brief, "tidies up things" so completely, that in a few years all traces of the rude work of the upheaving forces have nearly disappeared. Rounded hills appear in place of angular rocks, the valleys are clothed with turf, vineyards are growing on the crumbling lava, and corn on the soil which was raised out of the sea. This force is that of *denudation*, or uncovering, though in reality it strips the surface simply to enable it to convey the material to the places where it is most needed. It acts through the aërial elements, through rain, through springs, through rivers, through frost and frozen water, through the agency of animals and plants, and, when we leave the surface of the fresh-water world, through the sea which thunders on the shores which attempt to defy its inroads. The ocean sends up vapour which falls in the shape of rain. The rain sweeps over the ground carrying the soil with it, or sinks into the ground, to burst forth again in the form of springs, which bear with them whatever soluble material they have dissolved out of the rocks through which they have passed. In the end, both unite to form rivers which, descending to the lowest levels, join their forces and form floods, which roll to the sea through valleys which they are ever scooping out deeper and deeper. Into the river run mountain torrents laden with mud, which they have conveyed from the uplands as their contribution to the work of denudation, or the *débris*, which, by undermining the rocks so as to form landslips, they

* For these recent data we are indebted to a learned Tôkiô correspondent of the *Times*, January 7th, 1887.

have dislodged from the hills which to them are mere mounds of dirt to be duly returned to their pristine form of mud and sand. The sea then gains its own again, and stores up in the recesses of its depths the materials which are to be consolidated into rocks and, in the fulness of time, to be raised into the upper air again, to be in their turn attacked and duly demolished by "the elements," whose lives are spent in devouring their children. But the rain in the uplands and in the far north falls in snow, and the snow forms glaciers, which, grinding their way to the lowlands, bear with them the rocks and earth which they have torn from the side of the valleys through which they have journeyed, and deposit them far from their *quondam* home; or borne on the surface of an iceberg—the broken-off end of a glacier which reaches the ocean—the rock floats to distant regions, until, by the melting of the raft, it is dropped in the bottom of the sea, to be in time exposed as a "travelled block" perched on a Highland hill, or among the quiet pastures of a New England valley. Or the glacier, grinding like some vast sinuous file over the rocks, erodes into powder the ground over which it passes, which—washed out from under it in the shape of a white mud—is deposited at the bottom of the inlet into which the seaward end of the glacier protrudes, or into the Alpine valley, where, the warmth being too much for it, it ends its progress. The wind weathers every rock it comes in contact with, especially if the wind is laden with moisture, and still more if it is aided by rain. The plants in search of food devour the soil and split the rocks in their eager search after it, and the coral polyp, ever intent in building up its wondrous reefs, seizes the lime which the rivers have sent into the sea, as the molluscs and other marine animals utilise this material for their shells and bones, in their turn when dead to send it back again to the waters, or to convert it in another form into solid rocks. The sea, ever voracious, is never at rest. Into its hungry maw it sweeps whatever has been rescued from its depths in the shape of the islands which the coral polyp rears, or the rocks which line its coasts; or in the North its waters freeze, and in spring do not bid a reluctant farewell to the Arctic cliffs without bearing off as their tribute the boulders of earth and stones which the frost has dislodged and landed on the "ice foot" below. Thus the world is constantly being sculptured by the hand of Nature. To this weathering, added to the volcano and the earthquake, and the secular oscillation, the circulation of matter is due. The remainder of this volume will, therefore, be occupied in considering, as fully as our space will permit, or the necessities of the case demand, the geological agencies thus briefly alluded to, and which, as we have shown in the Introduction to this work, play so important a part in the ceaseless unrest of the living earth. Compared with the havoc wrought by the volcano and the earthquake, the slow, gentle, almost imperceptible wear of "wind and weather," rain and running water, may seem insignificant. But, as we shall presently learn, in the aggregate they accomplish even more than the forces which strike the eye and impress the imagination more vividly (Fig. 130).

Rain and Springs: Formation.

When a shower of rain falls on the earth, what is not absorbed by vegetation runs either wholly or in part off the surface; or if the soil is porous and the fall very gentle, it is for the most part absorbed by the thirsty ground. But in neither case is it lost as a geological agent. If the earth is not protected by a dense carpet of vegetation, and, above all, by forest growth, which not only breaks the mechanical action of the heavy tropical downpours, but by forming a spongy carpet of fallen leaves and twigs, allows the water to ooze down as through a sponge, the ground is scored by the rushing rivulets of rain, and the earth and gravel often washed away. On the other hand, if the rain is permitted to quietly sink into the soil, it percolates through the strata, dissolving out in its course whatever is soluble, running down the slope of more impervious inclined beds, and eventually finding

Fig. 130.—EARTH PILLARS, NEAR KIOTO, SPITI VALLEY, HIMALAYA MOUNTAINS.

(After a Photograph.)

its way to the surface at a lower level in the form of springs (Fig. 132, A).

Springs.—This is the simplest form of these familiar accumulations of subterranean water. But it is evident that a spring of this nature must soon run dry. It does not run out quite so rapidly as the rain runs in, and in any case appears long after the surface drought has set in. But it cannot long survive the stoppage of the rainfall which feeds it. If, however, the rain sinks until it reaches a hollow in a rock, it will fill this hollow before overflowing, and if the outlet happens to be a crack, the spring continues to flow for a very long period. Such hollows are generally the source from whence a pump derives its supply, or into which the sinker of a draw-well drops after boring down to a varying depth. Sometimes springs may arise from water which has infiltrated into the soil from rivers at higher levels, as in the Vienna basin (Fig. 131), a section of which also illustrates most of the modes of spring formation.

The water which passes into the earth finds its way through grooves, clefts, and crevices. But much also works downward by means of capillary attraction. No rock is quite impervious to water, and when the strata or even the unstratified mass in the heart of a mountain are broken, it is usually found that they are more or less damp, or that moisture can be extracted from them (p. 111). Thus, though some of the materials composing the earth's crust are more pervious to water than others, all eventually give passage to it; hence the varying capacity of rocks for holding liquid, and the seemingly whimsical nature of springs in near neighbourhood to each other. But simple though this inference is, it was long held that springs originated from the vaporised water of the sea, condensed in caverns, or, as Aristotle taught, that their source was due to air condensed into water in subterranean chambers; it being left to Mariotte and Halley to demonstrate that the fall of water in the form of snow, rain, and dew, was sufficient to account for all the water of rivers and springs.

How deep water penetrates we do not know. Probably it sinks until the internal heat of the earth vaporises it, for the varying temperature of springs is evidently due to the fact whether in their course to the surface they come in contact with heated material, or are too shallow in their origin to acquire any warmth beyond that of the air or of the earth through which they course. In Misnia, in Saxony, water drops from the roof of a mine 1,600 feet deep, and, after prolonged droughts, numerous springs, known to be deep-seated, either become attenuated or cease to flow, but speedily revive after heavy rain. It is also a fact that where springs exist there is usually higher ground somewhere in the neighbourhood, from which the water may and probably does flow. During the dry season of August and September, 1881, the anthracite miners of Schuylkill County, Pennsylvania, had to depend largely upon the supply of water found in the mines.*

Amount of Water Discharged.—The amount of water discharged from springs varies, of

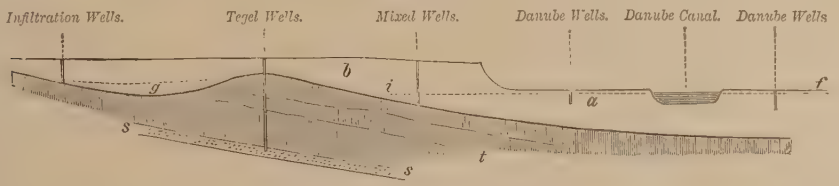


Fig. 131.—THE WELLS OF VIENNA.

a, Alluvium; *b*, Diluvial terraces; *c—f*, Infiltration water from the Danube; *t*, Calcareous clays (Miocene)—The "tegel" of the Viennese; *s*, Water bearing sand and gravel; *g*, Water accumulating in the hollowed rock.

* *United States Geological Survey of the Territories*, Part II., 1878, p. 357.

course, in accordance with the rain supply, the feeders of the reservoir, its capacity, and the size of the outlet. Two hundred thousand gallons are no unusual quantity of water to be poured from a spring, and in Central France, 231 springs have been gauged, and yield 2,628,000 gallons every twenty-four hours, while 180,000 gallons are poured daily from the Bath spring, though this supply has been yielded without any diminution for a time as far back as history extends. The warm springs of Georgia discharge 1,400 gallons per minute, and those of Bath County, in Virginia, yield not less than 6,000 in the same space of time;* while the upper springs at Banff, in the Canadian Rocky Mountains, have been calculated to discharge fully half a million gallons per minute. It is thus clear that the endless geysers and other hot springs must deprive the earth of an immense amount of warmth, and that when, as happens with many both cold and thermal springs, they are laden with silica and carbonate of lime, their agency in dissolving out and depositing elsewhere the materials of the earth's crust must be considerable. Added to this fact, many springs—"mineral waters"—are charged with iron and other materials which they have taken up in their course to the surface, and which extraneous materials constitute their value for medicinal purposes. Indeed, it is scarcely necessary to add that the varying composition of all springs and wells is due to the matters which they dissolve out of the earth or out of the rocks, for rain-water is perfectly pure.

Surface wells vary with the varying supply of moisture to the surface, and the streams fed by them are equally subject to the influence of the passing showers. They are too shallow to store any great reserve of water; their chief value is simply in gathering the drip into hollows and keeping it of a more uniform temperature than the rivulets exposed to the sky. Wells at a greater depth are less capricious, both as to supply and to temperature. But it is only those which derive their supply from the reservoirs accumulated in rocks at a considerable depth which can be reasonably relied upon. Their warmth depends on the depth at which they are found. It coincides with the temperature of the rocks which hold the water. This permeability of strata by moisture renders shallow wells and springs liable to pollution from sewage, or other impurities which work downward through the same channels through which the water is conducted, or which the water meets with in its course through the soil. Cholera, for example, is almost invariably propagated through polluted water. On the other hand, some strata—such as sand—filter liquid of any mechanical impurities, though it is impossible for organic foulness, such as the germs of disease, to be taken out of the water by this means.

Various Forms.—Again, it often happens—as, for instance, with most of the springs in the chalk region of the Eastern Alps—that the rain (Fig. 132, B) sinks down through the porous chalk until it reaches an impervious clay,† when it accumulates and rises up until it saturates the chalk to the line U Q., when the overplus of water is discharged in springs at both sides of the valley. This, indeed, will sometimes happen even when the impervious water-stopping bed slopes, but in that case the spring at the upper end of the line of saturation will run dry more quickly than the one at the lower end of it, and the upper surface of the saturated bed will be in a curve. If there is a break in the spongy overlying stratum, then the springs will (Fig. 132, C) burst out whenever the line of saturation reaches this crack.

Springs sometimes rise on the surface in a place where they could scarcely have been looked for. In these cases we may shrewdly infer that the water in working down through gravity has met with a fault or some other dislocation or irregularity of the beds not suspected, which has turned it out of its course. In other cases, we know that water in

* Walton: "The Mineral Springs of the United States and Canada" (1873).

† The adjective impervious, the reader will understand, is employed in a comparative sense only. No rock is really impervious to water, though many clays are so practically impenetrable by liquid, that they are used for puddling purposes, *i.e.*, to make basins, etc., "water-tight."

sinking down through a crack will in time be prevented by the gradually narrowing diameter of the fissure from proceeding farther in that direction. But it may happen that almost continuous with the original crack another will be found into which the water will run, and thus, finding no passage downward, it will rise to the surface by the hydrostatic pressure of the water above and behind it, even though the course described is in the form of an irregular curve, or, it may be, of a siphon. If the crack through which the water descends be of great depth, the column will be of corresponding weight before the fissure gets so narrow that farther progress downward becomes difficult. In this case, the water would most likely be warm when it issued through the other leg of the siphon—or, rather, through the second leg of the V—in a copious perennial spring, the warmth being due to the heat of the deep-seated rocks, and the copiousness and continuity of the flow to the great reservoir which so extensive a fissure must form. To this class belong many of the best known thermal springs, which are not due to the presence of volcanoes, such as that of Bath (117° to 120°). To this category also belong those of Baden (84·20°), and Vöslau (66·20°), as well as many of the still warmer "baths," such as Carlsbad (165·2°), Ofen (111° to 147°), Mehadia (104° to 147°), Wiesbaden (158°), Baden-Baden (111·20° to 154·4°), etc., from the temperature of which might, according to the rule usually adopted (p. 83), be approximately calculated the depth to which they extend.

Intermittent Springs.—Intermittent springs —that is, springs which alternately flow and get dry, or flow with more or less regular intervals of inaction — are due to various causes. The most common cause of a spring ceasing for a time to discharge, and then, after an interval, going on as before, is that its source is some hollow in the rock which only discharges when it overflows in the shape of waste water. The moisture, working its way slowly through the soil, is often longer in reaching this reservoir than at other times. Hence the irregularity of its overflow.* No doubt, also, some springs which owe to gases the motive-power by which their water is sent out from the reservoirs in which it accumulates will be intermittent. The water will, in such cases, only flow after a supply of gas has accumulated, followed by an interval proportioned to the time it takes for the motive-power to re-gather its force. Such springs are thus, in some respects, like geysers. It is more than likely that the "English Well" in the Canton of Berne, which flows for a few hours in the morning and a few hours in the evening, is of this character. The "May springs," which begin to flow in that month and continue until August, are due to the infiltration of water from the melting of the snow and ice in the comparatively low levels. In the same way, as I have shown elsewhere,† there are intermittent brooks in Eastern Oregon, due to the melting of the snows on the Cascade Mountains during the heat of the

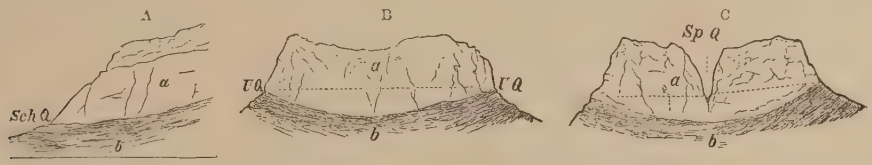


Fig. 132.—DIAGRAMS ILLUSTRATING THE DIFFERENT WAYS IN WHICH SPRINGS ISSUE FROM THE SOIL.

A: *a*, Chalk; *b*, Impervious clay; *Sch. Q*, Point where the spring issues. B: *a*, Chalk; *b*, Impervious clay; U Q, Springs issuing at either end of the saturated portion of the chalk. C: *a*, chalk; *b*, Clay; *Sp Q*, Fissure in the chalk which gives passage to the water out of the saturated portion of the chalk.

* The "nailbournes" and "winterbournes" of the South of England are springs which flow from the saturated chalk after periods of heavy rainfall (p. 270). They are, therefore, not really intermittent springs, any more than all springs dependent on the rain must be more or less intermittent, though some are practically perennial.

† *Journal of the Royal Geographical Society*, Vol. XXXIX. (1869), p. 130.

day, and the freezing up of the supply by the chill of the nights in that region. Sometimes, when travelling in the arid region at the eastern foot of the range mentioned, we would encamp in the forenoon by the side of a stream with barely sufficient water for camp purposes, but, on returning in the evening, would find it roaring and crashing along, so full of water as to render the fording of it a matter of difficulty, and again in the morning it would be almost dry, with the marks of last night's flood visible on the wet sand. The same phenomenon is to be seen in other parts of America,* as well as in various other regions of the world. I have seen muleteers near the basin of Mount Shasta (14,400 feet), in Northern California, waiting for the "rising of the creek" like the children of Israel for the smiting of the rock, and it was sometimes long after dark before the stream would be heard rushing down its former dry bed. So familiar was this phenomenon, that sufficient water for breakfast would be saved over night, knowing that the "creek" would be almost dry before morning. It is extremely probable that springs which look for their supply to similar sources will share in this intermittent flow. At Fontestorbe, in the Pyrenees, there is a spring which, during the summer months, alternately flows for 36 minutes 35 seconds, and then ceases for 32½ minutes. In wet weather, however, it ceases to be irregular or even intermittent. Near Brest is a well which sinks with the flow and rises with the ebbing of the sea. But now and then intermittent springs are perfectly regular, but change with the weather; and some have in course of time entirely or partially lost their peculiarities, flowing with little or no intermission, evidently owing to the wearing of the passages by the flowing water, or to some other alteration of the beds, to which they owe their special features.†

Submarine Springs.—Some of the underground supplies of water must be of enormous extent. This applies in an especial degree to those from which artesian wells (p. 273) derive their supply. London stands over one vast lake in the chalk, and in an artesian well sunk at Tours, leaves, stems of plants, and ears of grain tolerably fresh, came up with the water, which terrestrial relics were traced to the department of Ardèche, about 255 miles distant. It must also follow that springs will occasionally discharge under the sea. This occurs in the Persian Gulf, off the arid coast, near Bahrein. The boatmen take advantage of the fresh water bubbling up under the sea to dive down, and then speedily filling their goat-skin sacks, rise with the ascending current. These springs are probably from the same source as those which rise a little way inland, namely, the green hills of Oman, 500 miles distant. Both are tepid, and from their temperature are believed to rise from a depth of 800 feet. The Arabs imagine that this fresh water at the bottom of the sea is the material out of which the oysters make their pearls, and, Mr. Grattan Geary tells us, it is an ascertained fact that the best pearls are found after a season of heavy rains. Similar springs exist in the Gulf of Spezia and various points off the shores of Greece, though in the latter case they are cold, and, therefore, of shallower origin than those of the Persian Gulf. Though the sea can never be considered as the source of springs, there are circumstances which may cause them to rise and fall with the tide. For example, the tide may check the flow of a spring with an outlet near the sea-shore by ascending for a long distance up its channel. Thus, according to Mr. Cooley, in the military hospital at Lille, about 35 miles from the sea-shore, there is a copious well which has a daily and also a monthly variation. Its maximum discharge during the day, which is nearly double its minimum, occurs always about eight hours after high tide on the coast between Calais and Dunkirk. Finally, we may add, that springs in granitic regions—being, as a rule, derived from isolated reservoirs—are numerous, but not very copious, while those which permeate more porous rocks—being

* General Marcy narrates a similar observation when exploring the Red River of the South, but fails to account for the phenomenon.

† Cooley: "Physical Geography," pp. 250, 251, 253.

frequently in more or less continuous communication—are more abundant.

Artesian Wells.—When water-bearing strata take the form of curves, like so many bows lying upon each other, with their concavities to the sky, owing to the beds dipping towards each other, as in Fig. 133, the water accumulates in such a manner that an artesian well is possible. They are usually found in plains or basin-shaped valleys, towards which the strata dip on one or more sides, and get their name from having been long in use in the province of Artois (the ancient Artesium), in France, where one is known to have been in existence as early as the year A.D. 1126.

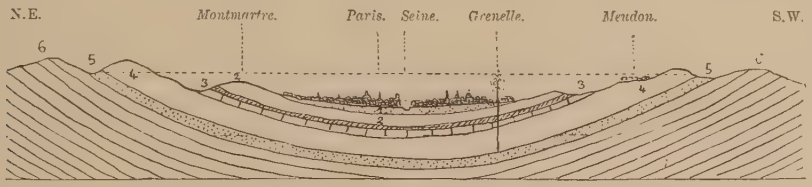


Fig. 133.—ARTESIAN WELLS AT GRENELLE, IN THE PARIS BASIN.

1, Alluvium and diluvium; 2, Upper Eocene; 3, Lower Eocene: the calcaire grossier; 4, The Upper (white) Chalk; 5, The Middle Chalk; 6, Greensand: The water-bearing beds; 7, Lower Chalk and Jurassic. The dotted line shows the level of the sea.

The principle on which they act is that the water, percolating through the upturned edges of the strata, finds its way down, when it accumulates in greater or less quantity, according to the greater or less permeability of the beds. But when a shaft or well is bored perpendicularly through the beds, the subterranean waters will immediately force themselves up through the opening, until, according to a well-known hydrostatic law—that water rises always to its own level—it attains the highest point of the water-containing strata. It also follows that the lower the surface of the artesian well, compared with the outcrop of the water-bearing bed, the higher will the jet rise above the surface of the bore. The force with which the water ascends is often very great. For instance, during the autumn of 1886 an artesian well in Belleplaine, Iowa, by the violence and copiousness with which it spouted, threatened, for a time, to do serious damage to the town. Its diameter was four inches, and when the depth of 181 feet had been reached in boring, a volume of water rose, and rushed up with such impetus that it formed a *jet d'eau* several hundred feet high. This gradually increased in size and volume until a stream of water 16 inches in diameter was formed, and the upward force of the stream was equal to the force of gunpowder. Two "gigantic rivers"—to quote the language of a correspondent—were accumulated by this outburst, which ran through the town at the rate of 12 miles an hour, carrying everything before them. The panic caused was naturally great. An attempt was made to insert 16-inch boiler tubes into the well; but these were instantly blown out and forced high in the air. Fifteen cartloads of stone were then emptied into the well; but these were tossed upwards as though propelled by a charge of giant powder. For several days the flow continued unabated, and then gradually subsided to the more moderate discharge now characteristic of the well.* There is, of course, only a limited amount of water in any water-holding bed, and though artesian wells flow seemingly without any abatement, their discharge is entirely regulated by the supply which flows in from the surface. In the London district the general level to which the water rises has been sensibly lowered by the many wells sunk in the Chalk, and in several where the water formerly rose to the surface, it

* *St. James's Gazette* (London), September 13th, 1886. There is a useful summary of all the essential facts regarding artesian wells, especially those of the London basin, in a paper by Mr. Hayward in *The Journal of Microscopy and Natural Science*, July, 1887, pp. 147—162.

has so far sunk below it, that the water requires to be pumped up. One great well will even exhaust several smaller ones at a less depth in its vicinity. For example, when an artesian well was sunk in the London Clay at Streatham (in 1885), the pumps at Tooting, two miles distant, ceased to draw, the shallower beds from which they obtained their supplies having been tapped. Water, however, percolates so slowly through some rocks, that cases are known of rivers fed almost entirely by springs flowing with undiminished volume after eighteen months of drought, the supply being derived from the intensely saturated beds of Chalk.

Some artesian wells are of great depth. That sunk in the Grenelle Basin, near the Hôtel des Invalides, Paris (Fig. 133), is about 1,800 feet deep; its bore is 10 inches, its discharge at the rate of 517 gallons per minute, and its temperature 82°. At St. Louis, in Missouri, there is one 3,843½ feet deep; but, owing to its having tapped salt-bearing strata, the water is saline. At Kissingen, in Bavaria, the salt spring throws up a column of water to the height of 58 feet from a depth of over 1,878 feet; but this is not properly an artesian well, for the projecting force is not hydrostatic pressure, but carbonic acid generated at the junction of the gypsum with the magnesian limestone at a depth of about 1,680 feet. But the deepest well in the world is that of Sperenberg (p. 84), near Berlin, (4,194 feet), which, sinking through immense beds of rock-salt, produces nothing but brine. An artesian well may be sunk whenever the conditions described are present. However, as these are chiefly in the Secondary and Tertiary formations, the London and Paris Basins, which are of these geological ages, are more penetrated with them than any other sections of the world. The Grenelle well we have already noticed. That of Passy, 1,700 feet deep, throws up 5,582,000 gallons per day to the height of 54 feet above the surface of the ground; and at La Chapelle there is one to be sunk to the depth of 2,950 feet; while another at Butte aux Cailles is intended to be bored to the depth of from 2,600 feet to 2,900 feet. As for wells of 500 feet and 600 feet, they are numerous all over the Paris Basin. The Tertiary strata upon which London and its suburbs are built is riddled with artesian wells. Here it often happens that a porous bed — sand, sandstone, or generally chalk—is included between two impenetrable layers of clay so as to form "a flat, porous U-tube, continuous from side to side of the valley, the outcrop on the surrounding hills forming the mouths of the tube." The water which has oozed in through the porous layer accumulates at the bottom in the shape of a subterranean pool, while "the liquid or semi-liquid column, pressing upon it, constitutes a sort of natural hydrostatic bellows," which causes so severe a strain on the superincumbent strata, that the upheaval or disturbance of the valley occasionally caused is so sensible, that some earthquake tremors may be due to this source. Naturally when this accumulation is tapped by the artesian borer, a rush of water to the surface is the result. Hence the ease with which excellent water is obtained out of the Chalk which lies beneath the London Clay. The source of the New River is a chalk spring near Ware, which yields 4½ million gallons a day; and many of the breweries, prisons, and public fountains (like those in Trafalgar Square) are supplied by these "blow-wells," as they are known to the people in the district between the Chalk wolds near Louth and the Wash. Two artesian wells at Croydon, in Surrey, yield a million gallons a day; and at Bourn, in Lincolnshire, the water rises to the tops of the highest houses. In China there are some which reach to a depth of over 2,800 feet, and of late years whole districts in the deserts of Tunis and Algeria have become green fruitful oases by the sinking of artesian wells for the purpose of supplying irrigation during the most parched season of the year and during exceptionally dry seasons.

It does not, of course, follow that if two impermeable strata with a porous one between them crop out around a basin, all the essentials for an artesian well are present. On

the contrary, if the permeable bed is either broken or interrupted, the water will not accumulate; and if the confining strata are in any way dislocated, they will not keep the water imprisoned. In boring, the lower confining layer must not be pierced, otherwise the water will escape and the well be destroyed, unless, of course, the conditions be repeated lower down, which they frequently are. Hence the necessity of a thorough survey of the geological conditions of the locality before a bore is attempted.

It follows from what has already been said regarding the gradual increase of temperature as we descend into the earth's crust, that the deeper the well the hotter the water. This, accordingly, is what we find. The temperature of some of these artesian bores has already been noticed (pp. 83, 84, 274). That of Kissingen is 66°, that of St. Louis 73·4°, that of Louisville 76½°, and one at Charleston rises to the temperature of 87°. Accordingly, the water from these wells has been utilised for the purpose of keeping up a uniform warmth in fish-ponds and cress-plots, and in heating hospitals and conservatories, while that derived from the one at Würtemberg is employed in maintaining a constant temperature of 47° in manufactories, even when the air outside is below the freezing-point. But, naturally, the principal purpose to which the water is applied is drinking, irrigation, driving machinery, or generating steam.

Rain and Springs: Erosion.

Rain, in falling on the surface or in sinking into it to form springs, or springs in traversing the under world in order to find an outlet, act in two ways. Firstly, they have a chemical action; and secondly, they act mechanically, simply by the friction which they cause, though it is not always easy to exactly define the limits of these two provinces. In reality, they generally act more or less in conjunction. However, for convenience' sake, let us examine the two separately.

Chemical Action.—It is not necessary to describe at any length the various mineral waters of the world, for, as the reader will already have seen for himself, if springs are derived from rain, or from the infiltration of rivers and lakes (which, in some cases, they may be, Fig. 131), they must in every instance have obtained their extraneous materials, their various salts, and other active substances, after they descended into the soil. In other words, they dissolved them out of the earth or the rocks through which they passed. All water, when it comes down from the sky—unless, indeed, it gets impure through the smoke of large cities—is absolutely tasteless. The colour of water, however, varies, though these tints are due either to the play of light or to foreign substances. When Padre de Acosta tells us that in Mexico he had seen "a spring as it were ink, somewhat blew; in Peru another of colour red like blood, whereupon they called it the Red River," the hue must have been owing either to the colour of the bottom or to various impurities, unless, indeed, the "blew" was due to reflection from the blue sky, and the red to transmission of light. Blue may be produced in water by exceedingly minute particles of any kind of matter. The blue colour of the Lake of Geneva has been proved to be due to suspended solid particles, so that, in all likelihood, pure water has no colour by diffusive refraction.*

But rain-water, in circulating through the soil to form springs or wells, and springs, again, in circulating through the earth in order to reach the surface, exercise an important action on the materials of the crust with which they come into contact.

The action of the rain which sinks into the soil is, in the first place, chemical. In itself it would not dissolve much except rock-salt and other salts (Figs. 134–136). But carbonic acid gas being freely absorbed by the water, in its course through the air or through the soil, it exerts a powerfully disintegrating action on the rocks, by rendering many substances soluble in it which would otherwise only be

* Tyndall: "Fragments of Science," p. 258; "Hours of Exercise in the Alps," pp. 463–470. Le Conte, in *San Francisco Mining and Scientific Press*, January 1st to February 12th, 1881, etc., etc.

mechanically affected by it. On calcareous rocks, in an especial degree, this acidulated water acts so rapidly that it soon honeycombs the bed, by dissolving out the lime and leaving the sandy or silicious matter, when this is present—as in "rotten-stone;" or it carries off chalk in solution and leaves

the plants. The rain-water also takes up a large quantity of oxygen, which oxidises or rusts any mineral matter with which it meets, and eventually dissolves or disintegrates it.

Granite, under the influence of rain, crumbles down. The felspar is decomposed, the silicate of potash is removed, the insoluble quartz and

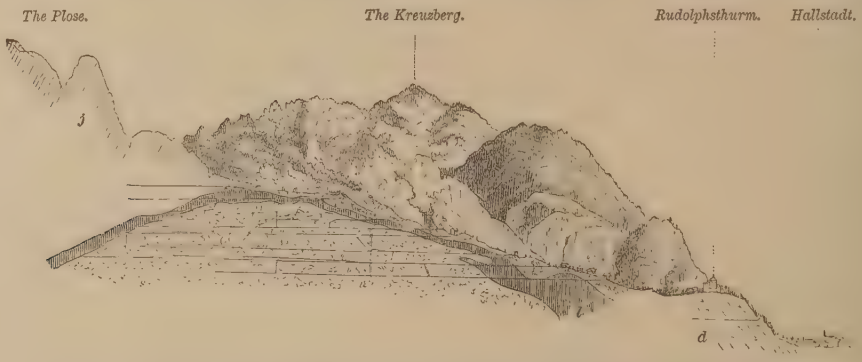


Fig. 134.—SECTION THROUGH THE SALT DEPOSITS OF HALLSTADT, IN UPPER STYRIA.

s, Rock salt; *l*, Dissolved brine; *d*, Dachstein limestone (triassic); *j*, Jura limestone.

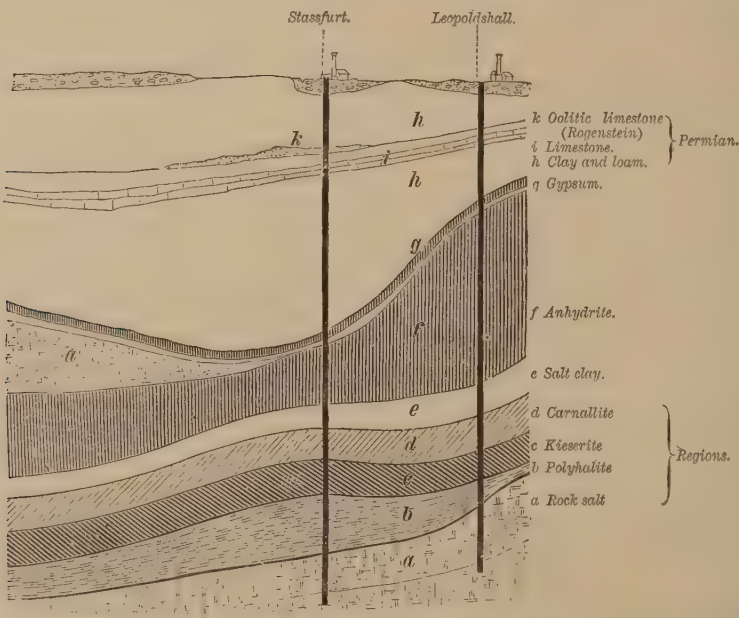


Fig. 135.—SECTION THROUGH THE SALT DEPOSITS OF STASSFURT, IN PRUSSIA, AND OF LEOPOLDSHALL, IN ANHALT.

mica being left untouched. By this time the hard granite is so loose that a spade can be pushed into it. Then, if the rock is on a slope, "spates," or the mechanical action of the rainfall, sweep away the loosened materials, depositing the silicate of alumina

Fig. 136.—CAVERN IN THE SALT MINES OF WIELICZKA.

(Kaolin or China Clay) here, the quartz in the shape of sand there, and so forth.

Caverns, Pipe Holes, etc.—But when the rain flows under ground in the form of a running spring, its effect on the soil is even more marked from a chemical point of view. It dissolves out the limestone until it forms great channels and caverns like those already described (p. 66), and uniting into considerable streams—like those which traverse the Peak Caverns in Derbyshire—flows in the shape of a river underground. Sometimes these caverns, hollowed out by springs, engulf rivers, like the Manifold in Staffordshire, which flows for nearly three miles under the earth, or the Aire in Yorkshire, which, in a portion of its course, runs through the underground cavity which ends at the foot of Malham Cove. In the Mammoth Cave of Kentucky there is an extensive underground river, the windings of which have never been fully traced. In like manner the River Poik runs through the famous Adelsberg Grotto (Figs. 28, 29). Sometimes part of the roof falls in, disclosing the stream brawling underground, and by-and-by, when the roof is not very thick and the rainfall has slowly disintegrated what the solvent power of the stream has left behind, it entirely falls in, leaving a valley or basin; and, in not a few instances, many of the curious "punch-bowl" like hollows one meets among limestone hills may be due to this cause. The amount of material dissolved out by some of the hot springs we have already referred to (p. 220). But many of the cold ones are not much behind them in this form of eroding activity. Volger, for example, has reckoned that the Lorenzquelle of the Leuk Baths (93°—123°), in Switzerland, washes out of the mountain enough gypsum in 600 years to make a cavern one foot deep over one square mile; but this is nothing to the hot springs of Warasdin-Teplitz, in Croatia, which discharge 462,000 gallons of water daily—at a temperature of 132° Fahr.—containing various soluble substances; or the Carlsbad springs, which, as we have seen, are even more powerful geological agents. It is therefore not astonishing to find extensive caverns formed in this manner, or that many of them—those of Carniola, for example—have extensive ramifications over a large extent of country. What are called "Pipes" and "Swallow Holes" are other instances of the chemical action of rain on limestone rock. If the rain collects in any little hollow it will gradually deepen it, or if it works in through the joints or through a crack the same result will follow. A funnel-shaped cavity, or "swallow hole," will be formed, to get filled up in time with the roots of plants, which will end in disrupting and widening the gap, or with earth and gravel from the surface. Good examples of these pipes are seen in the chalk quarries by the side of the Great Northern Railway at Hitchin.* If, on the other hand, there is no soil on the surface, these swallets, or pot holes—as they are called in Yorkshire—

* Jukes-Browne: "Physical Geology," pp. 86—92.

remain open, and not infrequently afford an opening through which the surface streams find their way into the ground. Many caverns begin with swallow holes; the water entering them, charged with carbonic acid derived from the air and the decay of vegetation, gradually works downwards, and excavates as it goes.

In the Karst (Tyrol) these pipe holes (which give a markedly honeycombed character to

Fig. 137.—PERPENDICULAR SECTION SHOWING "KARREN" EROSION IN THE LIMESTONE PLATEAUX (KARRENFELDER) OF THE ALPS.

this plain) are known as "dolinien" or "dolinas." They vary in size from some so small that they can scarcely be noticed to others as large as that of St. Kanzian, near Divazza, which is 525 feet deep. At the bottom of most of them is found a red earth —the *terra rossa* of that region—which seems to be the ferruginous residue of the limestone undissolved when the soluble portions of the rock were carried away by the rain and other eroding materials. In Northern Bohemia and Saxony another interesting example of rain corrosion is exhibited by what is locally known as "Karren," or "Schratten," in the limestone plateaux of the Alps, and in the "quader-sandstone" (Cretaceous) of Northern Bohemia and Saxony, both mechanical and chemical action having been long at work in forming them, the material which causes the erosion being, for the most part, the melting snow. Sometimes in this "Schrattenkalk" we find hollows which bear the appearance of having been caverns the roofs of which have fallen in. The "Karren" are often from 3 to 7 feet in depth, and occasionally they reach a depth varying from 13 feet to as many as 30, sometimes rounded, sometimes irregular, sometimes surrounded by rills, so that they form a glacier-like labyrinth. In all likelihood the Silbernalp and the Karrenalp of Switzerland have been formed in this way, though, of course, on a larger scale (Fig. 137).

Mechanical Action.—The mechanical action of rain is easily observed in the crumbling of the stones of which buildings are composed, and in the constant "weathering" which the sharpest mountain peaks undergo. The influence of this weathering in the formation of desert sands has already been noticed (p. 8). When a heavy shower falls we see how soon it sweeps the surface of any loose matter, the roadways being, after a sharp thunder "plump" washed almost clean. If this pour falls on a slope the result is still more marked, for the soil is worn into deep channels by the temporary streamlets, and, where it is not protected by dense vegetation, is often so completely swept into the valley below—where the stream carries it away and deposits it in another form elsewhere—that in tropical and semi-tropical countries it is by no means uncommon to see a hillside bare down to the "bed rocks," and what was not long before a fertile dale covered with a mass of *débris*. But the mechanical action of the rainfall is more marked in the slow wearing away which it causes, than in any such sudden violent action as that described. "Gutta cavat lapidem non vi sed sæpe cadendo" was a wise maxim of Ovid. "The rain-drop erodes the stone not by force, but by often dropping."

Earth Pillars.—This is seen in the curious earth pillars of Tyrol (Fig. 138), where all that is left of a valley once composed of hard clay and earth is a number of columns from 26 to 100 feet in height, each usually capped by a stone. The rain, working into the cracks in the indurated clay, gradually eroded the mass into the shapes it now possesses. The whole would long ago have crumbled into the mountain torrent which runs through the valley, had not the stones, which are thickly scattered through the clay protected the places in which they lie, until the rivulets trickling round them have left these stones capping the pyramids which in this way they have helped to form. When, as every now and again happens, the stones topple off, the pyramid—deprived of its protection—soon tapers to a

point, and by-and-by crumbles away. These facts are shown in Fig. 139.

Similar earth pyramids, more or less well developed, are seen in various places near Eisack (Katzenbach), and in the Finsterbach, near Klobenstein in The Ritten, Tyrol. An example of pyramids formed by the eroding action of rainfall is afforded by a spot near Kioto in the Spiti Valley of the Himalaya Range (Fig. 130). The "Eppelings" of Guiana (p. 43) are even more to the point, and Dr. A. Geikie has figured pillars in the old Red Conglomerate of Fochabers in Scotland, eroded by the action of rain into shapes almost identical with those figured from Tyrol. The rocking stones already described are also examples of the mechanical action of rain upon rocks (p. 91), and Dr. Bonney* will even have it that the Cheese-grotto of Bertrich-Baden (Fig. 50) is due to the gradual erosion of the material between the large concretionary masses which now form the pillars of the grotto. The "Bad Lands" of Wyoming Territory (Fig. 14) afford another type of erosion by rainfall. Originally a flat plateau of soft marls and sands, little, if at all, protected by vegetation, it is now furrowed into ravines, turrets, columns, and castle-like blocks of every fantastic shape, sometimes 60 feet in height, by the action of the rain and by the streamlets due to the rain, the showers often finishing off the outline of the rough forms thus blocked out. The isolated "Buttes" of Western America (p. 43), and—on a smaller scale, but identical in character—the detached knolls which Mr. Jukes-Browne has described in the soft Lincolnshire sandstones, might also be cited as specimens of the slow but powerful eroding action of rain. In the Northern hemisphere we can, however, form only a faint idea regarding the action of rain.

Fig. 138.—THE EARTH PILLARS OR PYRAMIDS IN THE VALLEY OF THE FINSTERBACH, NEAR BOTZEN, SOUTH TYROL.

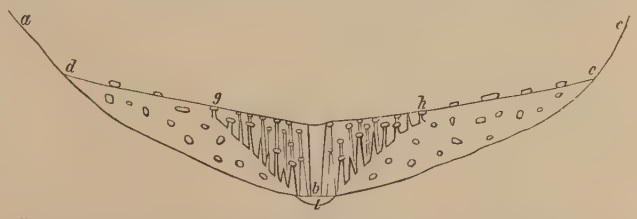


Fig. 139.—SECTION ACROSS THE VALLEY AT BOTZEN EXPLANATORY OF THE MODE IN WHICH THE EARTH PYRAMIDS ARE FORMED.

a, *b*, *c*, The sides and bottom of the valley; *d*, *e*, A mass of clay and moraine from an ancient glacier; *g*, *h*, *l*, The pyramids in process of formation.

* Bonney on "The Cheese-grotto of Bertrich-Baden," in *Science for All*, Vol. IV., p. 323.

It is in the tropics where its force is most marked. For instance, on the 31st of October, 1876, a terrible storm burst over the Philippine Islands, accompanied with perfect torrents of rain. These poured down the sides of the volcano of Mayon, sweeping before them the loose volcanic *débris*—cinders, ashes, and so forth—and ruining Manilao, Camalig, Ligao, Oas, Guinobatan, Libon, and other places. The bridges were broken down, and the roads blocked, while over six thousand houses were wrecked.

Landslips.—Rain, however, acts mechanically in another way. By oozing in between two strata lying in a slope, it washes out the material which holds them together; or by working in, let us say, between a mass of sandstone lying on calcareous clay, it will speedily so loosen the beds, that on the first impetus being given to them, the whole will lose cohesion and tumble into the valley below. This is known as a *landslip*, and is well known in the Alps and other lofty regions, especially in the spring or after long rains and the thawing of the winter's snow. After a long spell of dry weather, followed by continuous rains, a landslip is particularly apt to occur. For the rain pours into the cracks in the soil, and thus more readily than otherwise separates the beds.

A landslip is thus in many respects like an avalanche. In its simplest form, it consists in the superincumbent layers of earth and rock sliding over those beneath them, when, by the percolation of water, the junction between the different beds has been loosened. After the long Alpine winter the melting snow oozes into the beds, washing out the loose sand or ill-compacted limestone, and then the strata, nothing holding them together, slide down by mere force of gravity, carrying with them vast quantities of material resting on their upper ends, and bearing before them trees, rocks, and houses, which stand in their course. In August, 1826, after two dry seasons, there was such a landslip on the banks of the River Saco, in New Hampshire. Immense masses of rocks were detached, which swept down the steep slopes with such fury, that forests of firs were prostrated before the onset with as much ease as if they had been fields of corn. And what this avalanche of stones left undone, the bursting of the lake temporarily accumulated behind the barriers thrown across the streams accomplished even more completely. Earthquakes may, of course, precipitate a catastrophe of this kind much more speedily, and where springs hollow out the ground into caverns, either by dissolving out rock salt, or by the method already described (p. 226), the ground may suddenly give way.

But the ordinary cause is that which we have briefly indicated. It is daily at work on all the Swiss mountain slopes, and the history of the Alpine Republic is studded with tales of such catastrophes. As early as 563, Taurentum, a flourishing Roman town on the southern bank of the Lake of Geneva, was overwhelmed by a landslip from the mountain in the shadow of which it is built; and near Flims there is a confused mass of stone and earth 2,000 feet high, which seems to be the remains of a landslip before the Glacial period. Many of the Swiss villages exist almost on sufferance. The avalanche of snow or the avalanche of earth may at any moment sweep them away, or, what is equally ruinous, overwhelm them with the *débris* of the mountain at the foot of or on which they are built. In not a few instances the landslip is so slow in its progress that it is only a question of time when the final catastrophe will be precipitated. At Bec Rouge in the Tarantaise, for example, the side of the mountain is gradually overwhelming the village of Mirior. In most cases, however, the calamity is sudden and unexpected. Such an instance is supplied by the fall of the Rufi or Rossberg, a well-known mountain, 5,141 feet high, situated just behind the better-known and loftier Rigi. In September, 1806, after a very rainy season, a large portion of the mountain, consisting of beds of hard sandstone and pudding-stone resting on soft sandy layers, suddenly swept across the valley of Goldau, burying four villages, comprising over 300 houses, nearly 500 inhabitants, and more

than 85 square miles of fertile land. It filled up about one-fourth of the Lake of Lowerz, the sudden rise of which occasioned disasters in parts of the valley which had escaped with comparatively little injury from the landslip itself.

In September, 1880, by a landslip at Naini Tal in the Himalayas, a large portion of the station was carried away, and thirty-eight Europeans were buried beneath the rubbish. In 1248 part of Mont Grenier, south of Chambéry, in Savoy, fell and buried five parishes; while in 1772 a portion of the mountain of Piz, in the then State of Venice, slid down into the valley below and overwhelmed three villages with their entire population.

In 1855 a mass of rock and earth slid into the valley of the Tiber, which, dammed back by the obstruction, overflowed the village of San Stefano to the depth of 50 feet, until the drowned village was relieved by means of a hastily-constructed canal. Another example of a disastrous landslip is that in which, by the sliding of a portion of Monte Conto, the entire village of Plurs, with 2,430 inhabitants, was in 1618 overwhelmed. For several days before the catastrophe masses of rock had become detached from the mountain, and numerous fissures were observed to form or widen on its sides. But the villagers disregarded the warnings, and were in a few minutes buried with all their possessions beneath 60 feet of rock and earth. All attempts to penetrate the mass proved fruitless, and no trace of the town has since been seen. The earth which entombed it is now clothed with a luxuriant forest of chestnuts, but the original name still survives in the little village of Plurs or Piuro, which tourists know as the site of a manufactory of little articles in soapstone, which Pliny speaks of as the "Lapis comensis."

In 1512 a mass of rock fell from Monte Crenone, above Biasca, which destroyed 4,000 houses and killed 600 people. The River Blegno, dammed back by it, formed a lake, which did not burst the barrier for three years, when the whole country down to Lago Maggiore was devastated by the floods. The Lakes of Derborence were formed by the barrier thrown across the River Liserne by falls from the Diablerets, three of the five rocky peaks of which have given way. But though an attempt has been made to regard rock avalanches of this kind as different from those due to landslips,* this is impossible, for in both the loosening power of water is the chief cause which leads to the *débâcle*.

It may, however, happen that when the thick *débris* on a mountain side gets saturated with water, after heavy rains, it will slide down a slope, owing to the increased weight of the mass overcoming the friction which has hitherto kept it in position. But, even then, the infiltrating rain has helped to weaken the retaining power of the beds. A case of this character may be cited from the village of Feton, in the Lower Engadine. According to Heim, houses are tilted, or split asunder, and the detached granite rock on which the church stands is said to be slowly sliding downwards with the lower material in which it is embedded. The "Muren," "Murbrüche," or "Schlamströme," of the Tyrolese, are landslips of another, though an exceedingly interesting character. They are caused by

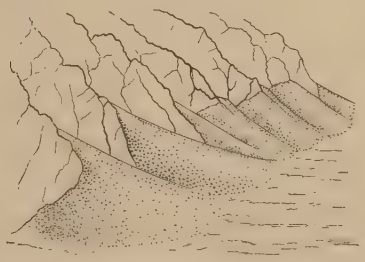


Fig. 140.—THE "MUREN," OR THE MUD STREAMS OF THE ALPS.

porous strata getting so thoroughly saturated by moisture from rain and other aërial water

* Baltzer, in his work on the subject ("Ueber Bergsturze in den Alpen," 1875), classifies them into four groups, (1), rock falls; (2), earthslips; (3), mud streams (Fig. 140); (4), mixed falls, on which earth, stone, and rocks, tumble indiscriminately. These are most common, though in reality the categorical classification is quite unknown in Nature. It is a book student's system.

supplies, that they are almost pulpous, and become crushed into mud by the superincumbent strata, and move down the mountain sides in lava-like streams (Fig. 140).

These catastrophes are so frequent that history preserves the memory of only the most disastrous. Such a one was that by which the village of Elm was overwhelmed on 11th of September, 1881 (Fig. 141). At that time the place contained 50 houses and nearly 250 inhabitants, most of them children and old people. Nearly half of them were

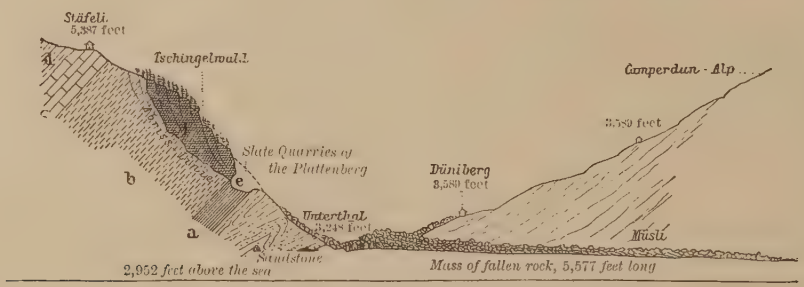


Fig. 141.—SECTION SHOWING THE LANDSLIP OF ELM.

a, Eocene slates; *b*, Shales; *c*, Nummulitic limestone; *d*, Shales; *e*, Removed mass of strata; *f*, Strata fallen down. (*After Heim*).

killed, while most of the dwelling-houses were altogether crushed or buried beneath the *débris* from that portion of the Tschingel Alp which broke away from its parent mountain. Altogether, though the Elm catastrophe was, in the loss to life and property, of less magnitude than those which overtook Plurs and Goldau, it is doubtful whether it did not, in the amount of rubbish shot from the mountain side, surpass both of these gigantic landslides. Professor Heim, who visited the spot immediately after the disaster, calculated that at the lowest estimate the contents of the slip measured ten million cubic mètres.* What a vast amount of material this pile contains may be grasped by a simple illustration. Zurich is a city of 76,000 inhabitants. Yet in the *débris* shot from the side of the Tschingel Alp there was stone enough to build two Zurichs. Some of the blocks are heaped 300 or 400 feet higher than the village of Elm. One is estimated to weigh 3,000 tons, and as

* A cubic mètre is equal to about 35·28 cubic feet.

these gigantic missiles were precipitated from a height of 2,000 feet, the irresistible force with which they fell on the doomed villages can easily be imagined.

In June, 1887, another fall, scarcely less disastrous, happened in the Schächenthal, a small but very beautiful side valley of the Reussthal, which opens immediately behind Altorf, the capital of the Canton of Uri. By the sliding of an immense mass of rock and earth from the Spitze, a mountain of moderate elevation, several houses, with their inmates, were buried in or about Spiringen. The darkness caused by the black dust resembled that of a London fog, and a peculiar smell filled the air, the result evidently of the enormous friction of the falling mass of rock. An eyewitness, on whose account we have drawn, describes the noise of the tumbling stones as, at times, deafening. The whole black slope seemed alive from top to bottom, with rocks flying about in all directions. Sometimes a number of large blocks would detach themselves from the top, shoot horizontally into the air, tumble against each other, and disappear again in the dark clouds of dust below. During the day the noise never ceased, and frequently during the night the din began again. Next day the result was evident in the lake which had formed from the temporary embankment of the River Schächen by the materials which had tumbled athwart it, and in the ruggedness of the landscape in the immediate vicinity. The rocky masses fell from such a height that it was found they had acquired so great a

momentum that they rose to a considerable elevation on the opposite mountain slope of Windgelle, and buried several cottages that had stood there. For a time the Schächenbach torrent was dammed, but eventually it forced its way through the obstruction, carrying with it much mud, many stones of large size, and pine-trees. As generally happens before a landslip, the stones had been coming down for many days previous to the catastrophe. But callous by familiarity with danger, the people of Spiringen did not pay much heed to these warnings. The mountain, indeed, has always been recognised as dangerous; that part of it which fell was known as the "Faul Flüh," or Rotten Cliff. Still more recently—in July, 1887—by the sliding of a part of Zug into the lake of the same name, many houses and huts disappeared, among them a four-storeyed hotel, with a large portion of the neighbouring street, and a quay only lately built. The annals of the town tell of a very similar catastrophe in 1435.

The saddest feature about these disasters is that there is no preventing them. A rebellious stream may be embanked, a treacherous sea may be dyked: but what bulwark can an Alpine village erect which could for a moment bear the brunt of such artillery as 360,000,000 cubic feet of stone and earth, with bolts weighing 3,000 tons, shot from a height of 2,000 feet? It is simply impossible either to guard against these landslips, or to oppose them when caution is no longer of any avail. The villagers—as we have seen—sometimes get an inkling of what is coming, though, as a rule, the slide is so sudden that until the roar of the fatal crash sounds in the ears of the doomed people they are scarcely conscious of the fate which awaits them. But even when they are forewarned, they generally hesitate to leave their homes, their farms, and their little all, on the mere chance of a calamity which, after all, may never arrive.

In England there are plenty of landslips, but they rarely do more damage than destroying a railway embankment or tumbling down a sea cliff. The worst of which history preserves any record is that by which, in 1839, after a long spell of wet weather on the Dorsetshire coast, a mass of limestone—1¼ miles long and 600 yards broad—slipped over a bed of clay into the sea, bearing with it houses, roads, and fields, though the mischief done was, in this instance, less than in any of the Swiss slides noticed. In 1886, after an unusually heavy rainfall, there was a landslip near Cimarron, in Colorado, involving an area of nearly two square miles.

The Undercliff of the Isle of Wight is in reality a succession of landslips, caused by the pervious chalk and greensand sliding over the impervious beds of "blue slipper," the clay on which they reposed when undisturbed. The different terraces are the result of the different landslips (Fig. 142). Similar occurrences might be quoted from the records of many other parts of the coast, and here and there we come upon geological evidence which entitles us to infer that long before History kept any chronicle of these disasters, they were going on in that steady systematically unsystematic way which Nature loves.

Valleys may, under certain circumstances—the "Plaike" of the Salzach, near Embach, above Lend, for example—be formed by landslips, aided by the erosive action of water subsequently acting on them.

Falkland "Stone Rivers."—Another curious illustration of weathering mainly by means of rain is afforded by the "Stone Rivers" of the Falkland Islands. On the East Island the late Sir Wyville Thomson describes most of the valleys as filled by these pale glistening masses, from a few hundred yards to a mile or two in width, which look at a distance like glaciers, descending apparently from the adjacent ridges, and, fed by tributary streams, gradually increasing in volume, until they reach the sea. Examined more closely, they are found to be vast accumulations of blocks of quartzite, irregular in form, but having a tendency to a rude diamond shape, from two to eight or ten feet in length, and half as much in width, and of a thickness corresponding to that of the quartzite bands in the ridges above. All the blocks being angular, like the fragments in a breccia, they rest irregularly one upon

another, those above supported in all positions by the angles and ridges of those beneath. Except that the surface is worn by the action of the atmosphere, they are not abraded to any extent, and a thin, extremely hard white lichen, which spreads over nearly the whole

great wonder by the shifting population of the Falklands, and are shown to visitors, with many strange speculations as to their mode of formation. Yet, in spite of the numerous theories which have been hazarded regarding their origin, it seems that the real one is not very

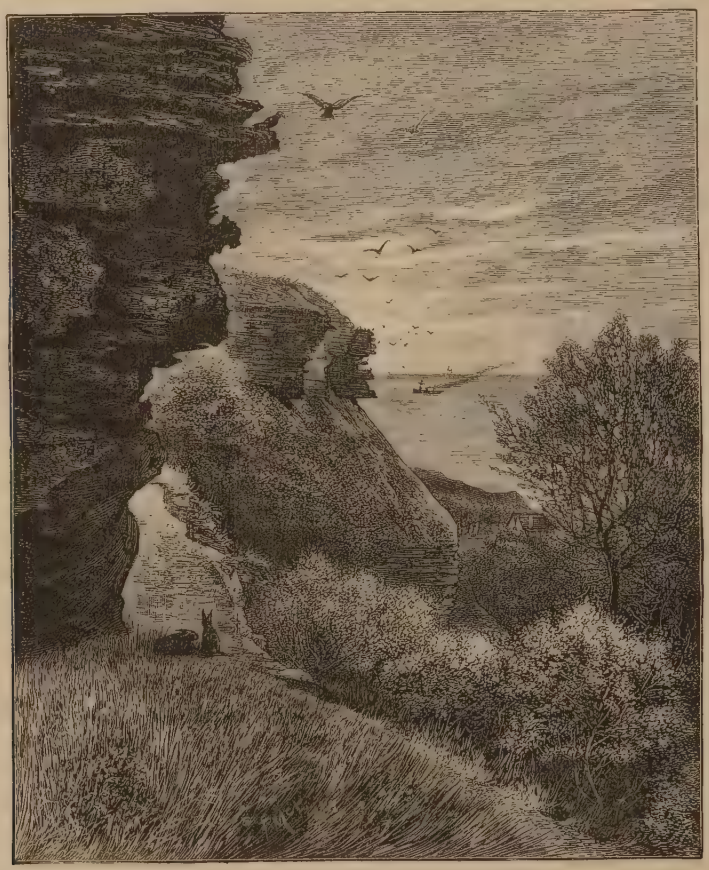


Fig. 142.—THE UNDERCLIFF, ISLE OF WIGHT.

of them, gives the effect of their being covered with a thin layer of ice. "Far down below under the stones one can hear the stream of water gurgling, which occupies the axis of the valley; and here and there, when a space between the blocks is unusually large and clear, a quivering reflection is sent back from a stray sunbeam."

These "stone rivers" are looked upon with

far out of the beaten track. "The hard beds of quartzite are denuded by the disintegration of the softer layers. Their support being removed, they break away in the direction of the natural joints, and the fragments fall down the slope upon the vegetable soil. This soil is spongy, and, undergoing alternate contraction and expansion from being alternately dry and saturated with moisture, allows the heavy

Fig. 143.—LAS CASAS DE SAN PEDRO EN CAQUENSES, IN THE CHILIAN CORDILLERA.

(*After a Photograph.*)

blocks to slip down by their own weight into the valley, where they become piled up, the valley stream afterwards removing the soil from among and over them." This explanation of Sir Wyville Thomson's, though possibly not quite so convincing as its author believed it to be, may in the present state of our knowledge be regarded as the nearest approximation to the truth which has been reached. It is certainly more satisfactory than Mr. Darwin's

this subdivision is not of extreme importance. Hence we may cite the cyclopean-looking collection of rocks which is often seen on the summits of hills, simulating to a passing observer ruined castles, as one of the effects of rain combined with the moisture of the atmosphere, the action of frozen water during the winter, and the alternations of heat and cold all the year round.

These "Felsmeere" (Fig. 144), "Blockgipel,"

Fig. 144.—PART OF A "FELSMEER" IN TYROL.

idea of their conveying to the mind the notion of some great convulsion having been at work. Yet the processes described must have taken an enormous time, though something very similar has been noticed, not only in that quarter of the world—in Patagonia for example—but also in the West Highlands and in other sections of Europe.*

"Devils' Castles," etc.—Weathering is so complicated an operation—so many elements enter into it—that it is not always possible to affirm with accuracy which plays the most important part. It is also difficult to say where the operation of rain ends and where that of springs begins, or where springs have finished their work, and the rivers, which are only collective springs, have taken up the task. Indeed, "Denudation," or "Ablation," is a comprehensive and not always clearly applied term. However, in a treatise which is less geological than geographical, and where minute details are not so much aimed at as broad sketches,

or "Stiper," to use some of the many names applied to them in the German Alps, have already been referred to in considering the character of granite (p. 92, Fig. 47). They are usually composed of blocks of granite syenite, porphyry, and similar hard rocks, through which joints run. In most cases they are remains of great dykes which have run through softer strata. In the course of time the latter beds have been weathered into their primitive sand, clay, or lime, while the harder dyke has withstood the action of the rain, the snow, the frost, and the wind. But even they must in time yield. The water works its way into the joints, and rives the blocks asunder and disintegrates the materials of which they are composed, in the manner we have already considered. The result is that the angles become rounded, and here and there spaces appear between the great pieces, so that they look as if they had been chaotically heaped on one another, though it will be found that the top ones, being most exposed to weathering, are most broken up, while the bottom ones, being more protected, are larger

* Thomson: "The Atlantic" (1877), Vol. II., pp. 245–249; Coppinger: *Quarterly Journal of the Geological Society*, 1881, p. 348.

and more solid (Fig. 144). These "Devils' Castles," "Devils' Cheese-rings" (Fig. 145), "Devils' Dykes," "Grandfathers' Chairs," "Kings' Stools," "Lovers' Seats," and so forth —as they have been fancifully named—are thus due to simple natural causes, though the forms that they assume vary infinitely with the rock of which they are composed, gneiss having more bizarre forms than granite, wise, some of the sandstone "grey wethers" in the Ardennes, for example, becoming, Dr. Geikie has noted, "under meteoric influences a kind of lustrous quartzite"—the capricious power of being proof against the erosion or corrosion which has destroyed the rest of the rock to which they belonged being, no doubt, due to the peculiarity mentioned. Indeed, though, as a rule, hard rocks decay more slowly, it is

Fig. 145.—"THE DEVIL'S CHEESE-RING," LYNTON, DEVONSHIRE.

trap more wall-like and less fantastic than either, and so forth (Fig. 143).

The "grey wethers"—as certain scattered and apparently isolated blocks found in various parts of England and the Continent are called—are really blocks of harder rock which have survived the destruction of the widespread beds of which they formed the component parts. In some regions they are found so abundantly on the Chalk, that it has been suggested they have been conveyed from a distance by ice or some other agency. Curiously enough, exposure to the weather has rather hardened these blocks than otherwise.

not always safe to reckon on their easy disintegrability being in a direct ratio to their softness.

These are, however, exceptions which need not interfere with the generalisation accepted as the truth. It is also notorious that while, as a rule, the action of oxygen and carbonic acid on the metallic ingredients of rocks (the iron, for instance) is to burst them in pieces, under other circumstances it will render the rock more durable. Bath stone, though permanent in Gloucestershire, perishes in Norfolk, and in the poisoned air of London few limestones long survive weathering.

CHAPTER XVI.

Rivers: Their General Characteristics

Rivers—Their General Characteristics—Their Sources—Catchment Basins—Watersheds—Not necessarily very High—Examples—Current of a River—Velocity—Back Flow—Alternating Flows—Diminishing Rivers—Sinks—Meandering Rivers—Tendency to Straighten their Courses—Cut-offs—Examples from the Mississippi and other Rivers—Deflection of Rivers by the Rotation of the Earth—Examples from Siberia, America, and elsewhere—Underground Rivers—Colour and Taste of Rivers, etc.

A RIVER is only a spring "writ large." Indeed, between a brook and the spring to which it owes its origin there is absolutely no distinction. Springs unite to form a rivulet, and rivulets feed rivers, and between a lake which interposes itself in the course of a river as a wider and deeper portion of the same water and the stream which flows through it—in at one end and out at the other—there is no distinction that can easily be expressed in a few words. However, it is unnecessary to define running, as distinguished from standing, water. Every one has an idea sufficiently correct for common purposes as to what is meant by a spring, a brook—the Scotch "burn"—the western American "creek"—a name applied by nautical surveyors to an inlet of the sea,—a river, and a lake.

Source.—It is always difficult to define the exact source of a river (Fig. 146). Water invariably running down hill, it follows that a river must rise in comparatively high ground. But a stream rarely owes its origin to a single spring, or rivulet from that spring, or other individual source. Its volume is contributed to by a great number of feeders, which are swollen by the rain falling within a particular "catchment basin." Into this catchment basin, or area, runs the drainage of a particular section of country, this drainage as a rule ending by many tributaries in one great river, which flows along the lowest level of the region which it drains. This basin is determined by a line drawn so as to take in all the sources of the tributaries, the waters of which end eventually in this main river, while the watershed, or divide of land, is the height which determines the direction which any particular set of rivers will take. Hence it is always over relatively, though not necessarily absolutely, high ground.

The "Great Divide" in Central North America is, for example, the saddle, on one side of which the rivers ending in the Pacific begin their course, and on the other those which terminate in the Atlantic. This watershed is, however, often not the highest point in any particular region. Rivers usually have their principal source in lofty mountains. But such mountains rarely form the watershed, for the simple reason that in chains of mountains, as Mr. Cooley aptly points out, the loftiest peaks are frequently in advance of the general range, and rivers which flow off in front rise in the rear. Their sources are among mountains from which they escape by winding round the greatest elevations. Thus, the Brahmapootra and the Indus rise in the lofty plateaux north of the Himalayas, and break through the mountains to reach the plain. Again, in the Carpathians, the source of the Vistula—which flows northward—is on the south, and that of the Theiss—which takes an opposite course—is on the northern side of the Tatra, the central granite range which rises from the tablelands of Liptau and Zips, which in their turn form the valleys of the Waag and Popper.*

* The Carpathians divide the vast steppes of Russia and the broad Hungarian plains. They form one of the climatic boundaries of Europe, and in accordance with what we have already said regarding physical features in determining the geographical distribution of races, the people on the south side of the Tatra are Slavonians, on the north, Poles, and in Zips, on the east side, Germans.

CORAL BANK IN THE RED SEA.

(AFTER HAECKEL'S "ARABISCHE KORALLEN" AND OTHER AUTHORITIES.)

It may even happen that a watershed has little elevation. A case in point is supplied by the isthmus which divides the streams which flow into the Gulf of Bothnia on the south, and the Arctic Ocean, east of the North Cape, in the contrary direction. Nor is the watershed between the Neva and other rivers falling into the Baltic, and the Icy Sea, and those which end in the Caspian and the Black Sea, much over 1,200 feet, while the portant river than the Mississippi before it joins to form the great flood which goes under that name; and, indeed, almost any of the larger tributaries better deserves the right of being considered the chief river than the one which originates in the little Minnesotan lakes. It is hard to say whether the Swale or the Ure is the source of the Yorkshire Ouse, or whether the source of the Rhine is to be sought in the Vorder- or Hinter-Rhein, or that

Fig. 146.—THAMES HEAD, A REPUTED SOURCE OF THE RIVER.

"divide" between the basins of the Mississippi and the St. Lawrence is so low that, at times of flood, canoes can pass from one to the other; while in Scotland, the Andes, Norway, and other parts of the world, the height of land is in places so flat that lakes and marshes on broad ridges of elevated land sometimes send rivers in opposite directions.

Tributaries.—It is still more difficult to define which particular stream is the main and which the tributary river. The broadest is usually taken as the head stream, though sometimes it is more convenient to accept the longest one for this distinction. This decision is, however, frequently very arbitrary. For instance, the Missouri is really a more im-

of the Danube in the Brege or up the Brigach in the Black Forest. The Marañon is preferred to the Ucayale as the head stream of the Amazon, though it is several miles shorter, merely because "the main direction of the river-course continues up the Marañon far beyond the confluence of the Ucayale, and the Marañon rises very much farther west than the Ucayale or any other affluent."* The Inn, at the point where it joins the Danube, is the larger river of the two, though

* Clyde, in *Scottish Geographical Magazine*, Vol. I., pp. 81–95. To this exhaustive paper of Dr. Clyde I must, once and for all, acknowledge my indebtedness. Many of the facts noted in this chapter have been derived from those brought together by this veteran geographer.

the united stream takes the name of the latter. In like manner, the Moldau, though really a greater river than the Elbe, has been robbed of the glory of being regarded as such. The sources of a river are, in fact usually very numerous: the main stream is like the trunk of a tree, its tributaries correspond to the branches, and their tributaries to the twigs.

Spring Sources.—These riverine tributaries originate in springs, in streams which flow from under glaciers (the Rhône, for example), or in lakes. But a lake is, generally speaking, merely a reservoir formed by a temporary accumulation of the waters of springs and rivulets, or a simple enlargement in a hollow in the course of a river. A stream may also originate in the melting of snows. But such a source cannot well be permanent, though, as we shall presently see, streams fed by melting snows are subject to periodical swellings and overflows when the banks are low.

One of the most copious spring sources in Britain was St. Winifred's Well, in Flintshire, which at one time* discharged 21 tuns (5,292 gallons) of water per minute. Of late years, owing to some of its sources of supply having been cut off, the discharge has declined to less than 12 tuns, so that steam-power is required for the work which previously was performed by the water-power supplied by the well, and by a brooklet which joins the well stream about fifty yards from the well itself. The fountain of Vaucluse is the source of the River Sorgues, which joins the Rhône five miles north of Avignon, and the Shannon "Pot"—the source of the river of the same name—is a large spring in a grassy upland.

It sometimes happens that considerable rivers spring almost fully formed out of the ground. A feeder of the Klamath Lake, in Southern Oregon — large enough to be navigated by boats—springs in this manner out of the soil near the old Fort Klamath, built in a basin surrounded on nearly every side by the Cascade Mountains, and therefore naturally abounding in springs. Mr. Joseph Thomson also mentions adult streams issuing from the base of Kilimanjaro, in Central Africa. In these cases we may suspect the presence of cavernous soil, and that the river is thus somewhat of the nature of those underground ones of which we have already spoken, and may have occasionally to refer to before we close our remarks on this class of phenomena.

Lake Sources.—It may even happen that a head stream originates in marshy ground soaked by oozing springs either from the bottom or from the higher ground, and that therefore it becomes difficult to fix upon any one as the source of the rivulet. Again, a river is erroneously said to originate in a lake when, in reality, the river merely flows through it—in at one end and out at the other—without its volume being much increased, except when the lake is surrounded by high banks, from which the melting snow in early summer contributes to the contents, or when other tributaries fall in. In such a case the lake basin is deep, and the outflowing river is merely the overpouring of the vessel. But when several streams of about equal volume feed a lake, the most considerable one by which the surplus is discharged may be said to originate in the lake, as not one of the tributary streams has a right to be recognised as the upper waters of the river. The lake in which the Scottish Spey arises is one of this description. So are Loch Maree the source of the Ewe, the little lake (Itasca)† in which the Upper Mississippi arises, and possibly Lake Lauricocha, the conventional source of the Amazon.

The River Course.—The character of a river depends mostly, if not entirely, on the character of the country through which it flows. If the water in sinking to the lowest level—which level is, except in very rare instances to the contrary—the sea, has to force its way through narrow mountain gorges, the chances are that the river will be narrow, swift, and unnavigable. If there is a sudden

* It did so in Pennant's day—one hundred years ago.

† The so-called Lake Glazier, over which there has been so much controversy, has no right to that distinction.—*Science*, Vol. IX., pp. 291, 418.

transition in different parts of its course from one formation to another, of a different degree of hardness, the probabilities are in favour of the current being interrupted by rapids; while, if it passes suddenly from one level to another a waterfall must necessarily break the even flow of its course.

Velocity. — The velocity of the current depends upon the steepness of the ground along which the river flows, and this necessarily varies in different portions of its course. When it comes down the mountain side it is usually a torrent, in the valley it may be swift or slow according to the gradient of the bottom, in the valley section of its course it is more placid, while in the plain it may crawl along with an almost imperceptible motion. The mountain torrent can scarcely be said to flow. It tumbles from rock to rock in picturesque cataracts, the fall being about one inch in a foot (Fig. 148). In the upper part of its course the Danube falls 26 feet in almost every two and a half miles, but lower down, near Ulm, the gradient is only 18 feet in the same distance. Again from Ingoldstadt to Ratisbon (47 English statute miles), it falls about 7¼ feet in every 2½ miles, and below Vienna to Buda-Pesth only one foot in the same distance. On the other hand, the fall of the Amazon in the last 700 miles of its course is no more than one-fifth of an inch per mile. The Missouri has a descent of 28 feet per mile, while the Thames has a gradient of 21 inches per mile, the Shannon 11 inches per mile, though in the upper part of its course it is nearly twice as steep. The Nile below Cairo creeps along at a slope of from 3·25 to 5·5 inches per mile; while the Volga, in no part of its long course has a steeper descent than 3 inches per mile. On the other hand, the Rhine, from Besançon to the Mediterranean, has a fall of 24·18 inches per mile, while the Arve at Chamonix is a torrent thundering down the slope with a fall of 1 foot in 616. A river to be navigable ought not to have a higher gradient than 10 inches for every mile.* When its fall exceeds one foot in a thousand it ceases to afford a waterway into the interior of a country.

The swiftest portion of any river is not at its surface,† immediately over the line of greatest depth, but at a distance about one-third of the way to the bottom. The mean velocity is about one-tenth of the depth below the surface, though when the wind blows up stream the strongest current is much lower down (Fig. 147). Mr. Cooley, who makes

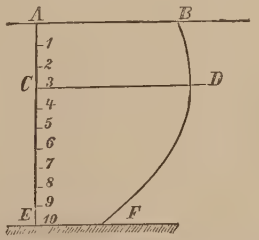


Fig. 147.—DIAGRAM SHOWING THE VELOCITY OF A STREAM FROM THE SURFACE DOWNWARD.

A—B, Surface of the river; C—D, Greatest velocity; E—F, Velocity along the bottom.

this statement, relates a curious practice suggested by this fact. On the Siberian rivers, most of which flow into the Arctic Ocean, the north wind, as might be expected, often prevails. When this is the case, the boatmen utilise the aid of the current by tying a large bundle of sticks loaded with stones in such a way that it is inclined to sink. This bundle, thrown into the water and carried down by the current, is prevented from sinking to the bottom by the rope which connects it with the boat's head. But suspended in the strong current it overcomes the resistance of the wind, and permits the vessel to drift seaward with the stream.

At the bottom of the river the velocity of the current is least. Again, in the centre of the current the velocity is greater than at the sides where the water has to overcome the friction of the banks, just as the bottom layer

* David Stevenson: "Canal and River Engineering," p. 229.

† Professor James Thomson (*Proc. Roy. Soc. Edin.*, 1878, p. 114) affirms that the greatest movement is in that portion of the water between the surface and the bottom layer, the surface water being retarded by upward currents caused mainly by irregularities of the bottom.

is retarded by having to overcome the friction of the bed. The velocity, we shall see, has an important influence on the capacity of the river for eroding its bed, and carrying forward the material which it wears out of the rocks over which it flows.

Fig. 148.—MOUNTAIN TORRENT IN SWITZERLAND.

Volume.—The amount of water in a river at any particular date depends entirely on the amount which its feeders may be contributing to the common stock, and their fulness of flow is regulated by the quantity of water which they receive from the rainfall, the springs, the melting snows, or other sources of supply. Hence a river is full in a wet season and comparatively empty in a dry one. But when it collects its waters from a wide area of country it is quite common for it to be "bank full" when not a drop of rain is falling along its principal course, or even when the entire basin drained by it is suffering under a long-

continued heat or drought. This is, in the first instance, owing to some important tributary being swollen by rains far east or west, north or south, of the main current; and in the second, to tributaries swelling in consequence of the melting of the snows in the uplands, or in the northern regions in which they rise. We see this in the case of the Nile, the Mississippi, and other rivers. The Nile, swollen by the spring rains of Abyssinia, inundates the plain of Egypt every summer at or about the same period. The height to which it rises in Upper Egypt is from 30 to 40 feet; at Cairo, lower down, the river is from seven to nine feet less, while in the Delta it is not more than four feet. In like manner, the Ganges, swollen by the melting snows of the Himalayas, begins to rise in April and continues to do so until the overflow floods the plains to the depth of some 30 feet. The lower Mississippi rises in December by the swelling of the Ohio, and in June, by the melting snows which pour into its upper waters. Then the low country on either side is entirely submerged, and the river itself is marked out only by the clear broad band of water in the midst of the inundated forests.

Freshets or "spates" also produce temporary overflows of much shorter duration, but, owing to their suddenness, of greater destructiveness. In Western Europe, for example, the Rhône sometimes rises 23 feet at Avignon, the Saône 24½ feet, and at Paris the Seine has been known to rise 20 feet above its average level, while during the inundations of 1827 the Ardèche at Gournier rose more than 69 feet. Floods are more frequent during the winter than the summer months, since, owing to the absence of evaporation, a greater amount of the rainfall finds its way into the river at that period than during the summer, when the thirsty soil and the abundant vegetation retain a large portion. All floods are, physically, due to the inadequacy of the river channel to carry off the unwonted supply of water within a given period. A river bed is formed and maintained by its stream, and is therefore only equal to discharging the ordinary amount which reaches it. Hence, a flood being too rare and of too brief duration, it cannot scour out a channel sufficiently broad and deep for its accommodation in the comparatively short period during which it lasts.

There are, however, other causes of floods. For instance, as Mr. Vernon-Harcourt has pointed out, a river deposits in the channel, whenever the current is checked, a large amount of the solid matter which it either washed from its banks, and which has been ground from the mountain rocks by glaciers, and swept into the river by the sub-glacial stream, or which its tributaries have eroded before they were lost in the main current they contribute to. This material consequently raises the river-bed and impedes the flow of the stream. Moreover, a river flowing

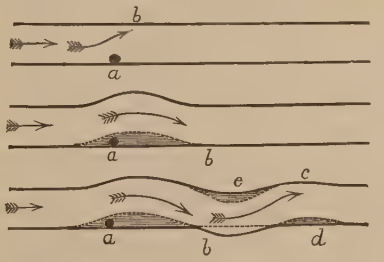


Fig. 149.—DIAGRAMS SHOWING HOW THE COURSE OF A BROOK GRADUALLY BECOMES ALTERED.

through a plain has a tendency to increase its serpentine course by excavating concavities on one bank and depositing part of the material thus eaten out on the opposite shore, which, by diminishing its fall, reduces its velocity. These facts—which will be again referred to when the erosive power of rivers is under discussion (p. 298)—are well shown in the diagram (Fig. 149) prepared to explain the gradual alteration in the course of a brook.

In Fig. 149 A we see that, no matter how straight a brook may be at first, a few detached sods (*a*)—whilst protecting the bank from which they have fallen, will throw the full force of the stream obliquely against the opposite bank (*b*)—which would soon be thus deeply cut into, whilst the current of the opposite side,

enfeebled by the impediments that deflected it from its direct course, and thereby losing some of its transporting power, would deposit its coarser sands (Fig. 149, B, *a*) on the protected side. These deposits then encroach on the water, and the water encroaches on the opposite shore. The bend thus produced increases in magnitude, and becomes a cause of similar action in the opposite direction (Fig. 149 B, *b*, 149 C, *b*), so that it must inevitably follow that the meanderings of the brook will steadily increase in number and magnitude (Fig. 149 C, *a*, *b*, *c*), whilst an interrupted series of sand deposits (Fig. 149 C, *a*, *d*, *e*) would be found behind each of its tiny sheltering headlands.*

Hence rivers, if left to themselves, tend to "deteriorate," from the engineer's point of view; the discharging capacity of their channels becomes less. The gradual silting up of the River Theiss near Szegedin, in Hungary, produced a rise in its flood-level, which led to the disastrous inundations of 1879 and 1887; and so extensively have some of the rivers of Japan been silted up, and the embankments protecting the adjoining country proportionately raised, that "some of these embanked rivers have their beds as much as 40 feet above the level of the plains over which they flow." In like manner, the bed of the Po has become higher than the adjacent land, so that, by simply opening sluices, the fat meadows of Lombardy and the rice fields of Venetia and Emilia are inundated. At the same time, it is certain that the increase of subsoil drainage, by sweeping the rainfall more rapidly off the soil, not only precipitates these floods, but, by stopping the supply to springs, renders summer droughts more frequent than they were when the country was left to the unaided efforts of Nature.

Periodical floods, however, as in the well-known case of the Nile, to which the fertility of Egypt is due, may be regarded as a part of the plan of Creation for utilising the surplus rain of the world. A river does not necessarily make a country fruitful. On the contrary, by draining away the rainfall, it may increase its aridity. In dry regions, like Northern Africa, the Cape Colony, and Southern Europe generally, the course of a river may be traced by the green vegetation which grows on either side of it, though this ribbon extends no farther than where the soil is moistened by the water oozing out from the river by means of capillary attraction. All beyond this narrow boundary is arid, except where it is irrigated: then its native fertility is at once apparent. The Plain of Shinar was at one time a fruitful garden; but, though the Euphrates and the Tigris flow where they always did, the irrigating works no longer existing, the land has reverted into its original condition of desert. When the Mormons first came into Salt Lake Valley, they found a trapper, well known to the writer, encamped on the spot where Salt Lake City is built. He laughed incredulously at the idea of the immigrants ever raising an ear of wheat out of the parched soil of that forbidding-looking region. But, by irrigation, it is now a fertile land; though outside the limits refreshed by the streams of water, the sage-brush (*Artemisia*), an unfailing sign of a parched region in that part of North America, may be seen close to the fence of a peach orchard or a field of grain.

When a river naturally overflows—*i.e.*, when it is not contained within embankments—the heavier sediment being first deposited, and the lighter carried farther off to be spread over a wider area, the banks close to the river are raised more rapidly than the country farther back, so that a sort of natural embankment is the result. The same law holds good regarding the silt deposited in its course. The finest materials are borne farthest; the coarsest are soon left behind; though the deposition does not usually begin until the speed of the river slackens, which is always the case when it arrives at the flattest country through which it flows before falling into the sea, this "champaign" being, in many instances, the offspring of the silt brought down by the river in former ages. (Fig. 150).

* Williamson: *Science for All*, Vol. IV., p. 121.

Diminishing and Intermittent Rivers.—When a river has no tributaries, its volume, instead of increasing the nearer it approaches the sea—which is usually the case—actually diminishes, until in dry hot countries the evaporation in its onward course is so great that its waters disappear before they reach that goal. This is owing to the fact that soil sinking down, to be stored up for the supply of water in the shape of springs. The Nile (Fig. 151) is an example of a river which diminishes towards its mouth. Its last considerable tributary is the Atbara, which joins it 120 miles from the Mediterranean, and during the months from March to June is little more than a chain of pools, the

Fig. 150.—THE MISSISSIPPI DELTA, FORMED BY THE MUD BROUGHT DOWN BY THE RIVER.

only a certain amount of the rainfall is discharged in this manner. Much of it is evaporated, and this evaporation of course holds good as to streams, as well as to other water supplies. The Thames* at Staines discharges 32·40 cubic inches per minute per square mile, or equal to less than a third of the rainfall, which is also the case of the Seine at Paris. But in the Mississippi (Fig. 150) basin only one-fourth is thus discharged into the sea. The same ratio of drainage to rainfall holds true regarding the Elbe in Bohemia. Much, however, depends on the nature of the soil—the rain which falls on hard impervious slate or clay running off the surface, that which drops on porous

* Beardmore: "Hydrology," p. 201.

haunt of crocodiles, hippopotami, and turtles. Hence, owing to this cause, as well as to the water withdrawn for irrigating purposes, the Nile diminishes below this point. From the confluence of the Panjnad downward the Indus gets smaller. In the interior of Australia and India some streams only flow after rains, or have—as in the former country—no regular channel, but in place of this there is a succession of flats liable to inundation. What are known in Western America as "sinks," are exemplified by more than one of the streams which lose themselves in the interior of Australia, and on the western slope of the Rocky Mountains are shown in the "sinks" in the dry desert country where the Carson and the Humboldt disappear.

Alternating Flow. — A curious feature, which Dr. Clyde has described as "alternating flow," is exhibited by Lake Ngami, a shallow lake in the southern part of Central Africa. "Its chief influents, Zouga from the south-east, and Tonke from the north-west, are in flood at different seasons. Zouga in flood avails to make the lake overflow into and up Tonke, which is then very low; Tonke in flood avails to make the lake overflow into and up Zouga, which is low in its turn. When Lake Ngami contains more water than to 4 feet deep, but in the wet season it serves as a backwater to the Mekong, until it attains a depth of from 40 feet to 50 feet, and, stemming the current of its own feeders, overflows the entire country for miles in every direction, and even shallow valleys not belonging to its own drainage.

The inflow of the tide, as we know from familiar observation, stems the down flow of most rivers. But the immense flood of the Amazon seems an exception to this rule. Yet at Santarem, 500 miles from the mouth, the

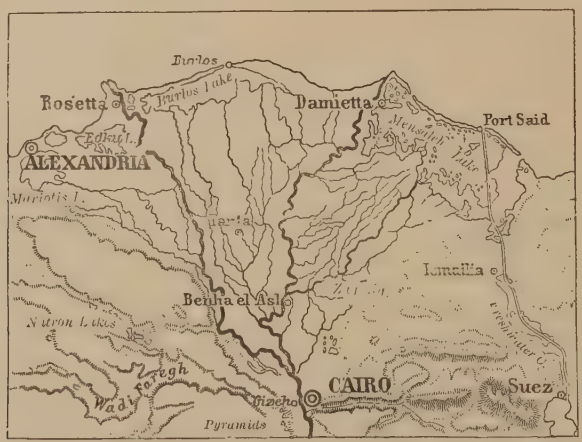


Fig. 151.—THE NILE DELTA, FORMED BY THE MUD BROUGHT DOWN BY THE RIVER.

can be disposed of by the alternating flow, the excess escapes northwards by an offset from Zouga called Malabe, which branches out so as to meet the Chobé, a tributary to the Zambesi, at five points. In the dry season the Malabe is waterless; in the wet season it flows north or south according as Lake Ngami is brimming to overflow, or not." In much the same way when the right bank tributaries of the Amazon swell the flood, the water presses up the left-hand tributaries which are then at their lowest; and in June the left-hand tributaries, swollen in their turn, send a like pressure up the right-hand tributaries, which by that time have fallen considerably.

The Tali-Sap Lake, on the confines of Cambodia and Siam, is normally only from 3 feet

river at 100 yards from its banks streams away seaward, evidently unaffected by the tide, though at that moment its side waters, raised by the upward current from the Atlantic, are creeping in a yellow volume up the blue Tapajos, which joins the Amazon at this point. The belief, therefore, is, that while the main current on the surface goes on uninterruptedly to the Atlantic, the tide creeps up along the bottom. When the main river—far beyond the reach of the tide—rises owing to a rainfall which has not reached the basins of its tributaries, there is a back flow of much the same kind as that described, though, of course, owing to a different cause.

One of the most remarkable instances of these back flows of rivers was afforded by the

Indus in 1858. In that year, owing to an obstruction similar to the one which occurred in 1841 (p. 306), the river did not rise so fast as usual. But on the 8th of August the pent-up waters burst their barriers and,

"Like as a water-streame whose swelling sourse
* * * * * *
Breaks forth, and makes his way more violent,"

rushed down with irresistible fury. At Attock the river rose to 80 feet above its low-water level. The Cabul River, which joins the Indus at right angles above Attock, was, at the time of the flood, coming down with a very uniform slope of two feet per mile. But on meeting with the Indus flood it was driven up stream at the rate of ten miles an hour. This back current, meeting the river coming down, caused the Cabul to overflow both banks with great force, and inundate the military station of Naoshera, which was almost destroyed. The people first got the alarm by seeing the river running the wrong way with a velocity greater than its downward current, but no exertion could avert the damage which followed. These floods are of frequent occurrence, though it is seldom that any of such severity as those of 1826, 1833, 1841, and 1858, have to be recorded. The obstruction which caused the flood of 1833 was due to the slipping of a glacier on the upper course of the Shayók River—the chief hill tributary which joins the Indus after a course of 350 miles. The other floods were caused in a similar way, though at different places. Mr. Hayward, in his explorations in Gilgit during 1870, noticed a temporary obstruction of this kind forming a lake in the Gilgit valley, in which valley also he believed the flood of 1858 to have originated, though it has been attributed with more probability to a landslip near the sharp southward bend of the Indus, 70 miles below Iskardo. A flood of a similar kind is said to have occurred on the Sutlej in 1872.*

Many rivers have permanently decreased from the causes already indicated (p. 8)—viz., the stripping of the country of timber—and in the Alps there are many circumstances which prove that torrents have existed in places where their deposits are now the principal evidence of their former ravages.† Finally, it may be added that there is every reason to believe that many rivers have, at some former period in their history, been much fuller of water than they are at present. Dana, indeed, in view of the many terraces or benches which exist on the banks of the American rivers—on a far grander scale than we know them in Europe (on the Fraser in British Columbia,‡ on the Mackenzie, and on the left bank of the Yellowstone in Montana, for example) — considers that they point to the gradual shoaling of the rivers during the elevation of the axis of that continent. In Morocco these benches are also to be found, pointing to many of the rivers of the western side of the Atlas having at one time been very much larger than at present.

Meanderings of a River.—The tendency of any river is to run straight down to the lowest level, and in the first portion of its course, where the stream is swiftest, and its force greatest, it is less frequently meandering than when it reaches flatter ground, and has less power to overcome the obstacles which deflect its current.

This feature may be seen in all rivers, from a brook to the largest current. The current pressing against one of the banks undermines it and forms a concavity by the "caving in" of the bank thus excavated, round which the upper layers of the river play freely, while the under currents carry the sediment to the opposite bank, thus protecting it, for a time at least, against attack. If the sediment thus tossed from one side to another is thrown against a ridge of rock it will accumulate in the form of what is known in the rivers of North Western America as a

* Maclagan, in *Proceedings of the Royal Geographical Society*, 1885, pp. 716-717.

† Croumbie Brown: "Reboisement in France" (1876); "Forests and Moisture" (1877); etc., etc.

‡ Robert Brown, in *Journal of the Royal Geographical Society*, Vol. XXXIX., pp. 121–131, and Vol. XLI., pp. 348–360; Begbie, in *Proceedings Royal Geographical Society*, Vol. XV., pp. 133–146.

"bar," projecting into the current; these bars —to be distinguished from similar accumulations at the mouth of rivers—being favourite spots for the lodgment of the gold dust swept down the river with the disintegrated rock in which it has been contained (p. 106). The "bars" of Fraser River were familiar to thousands during the years 1858 and 1859, just as those of the Sacramento and other Californian rivers were at an earlier or a later

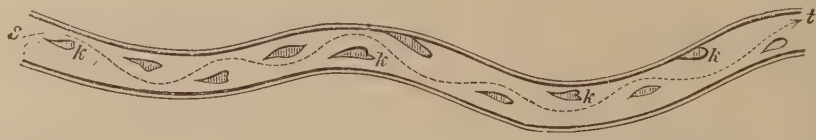


Fig. 152.—THE GRAVEL BANKS OF THE RHINE ABOVE GERMERSHEIM.

s—t, The "Thalweg" or centre of the river; *k*, The gravel banks and river "bars."

date. In the Rhine (Fig. 152) these gravel banks can be seen very well (p. 293).

Again, if the banks of a river vary in geological structure, the current, especially if it be tolerably swift, will "cannon" or re-

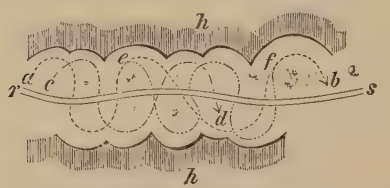


Fig. 153.—DIAGRAM SHOWING THE ALTERATIONS IN THE BED OF THE RHINE.

h—h, The higher banks of the river; *a—b*, *c—d*, *e—f*, The old serpentine windings of the river; *r—s*, The regular bed of the river.

bound from the hard rock on which it plays, comparatively powerless to the clay bank on which it works its will. In this manner the stream becomes sinuous, and naturally greatly increased in length, with the velocity of the current proportionately diminished, though of course the circuitous character of any river is primarily determined by the contour—the ups and downs—of the country over which it flows. The Rhine is a case in point (Fig. 153). The Devon is another example. From the spot at which it rises, inside the Ochils, to the point where it joins the Forth, the distance as the crow flies is only 6½ miles. Yet the course of the river is 26 miles from source to mouth. The Nile again, owing to the great bend from Korosko to Abu Hamed, makes the voyage by the river 500 miles longer than the journey across the desert. The Forth is another example of a meandering river. Any one who has ever sailed up to Stirling must remember the endless windings of the stream as it flows through the flat, rich "links" of its lower course. The steamer will sometimes be half an hour in winding round a peninsula which can be crossed in a few strides. These land loops form "aits," as often a link is completed into a loop, the tendency of the current being (Fig. 154) to cut through them and straighten its course, as in the case of the Rhine (Fig. 153). Between Stirling and Alloa the "Scottish Meander" winds along for 20 miles, though in a direct line the distance is not over seven miles.

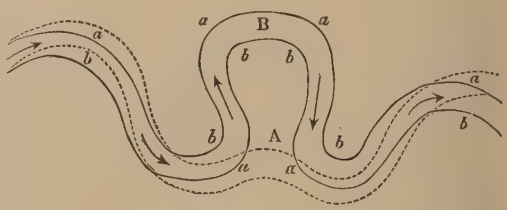


Fig. 154.—DIAGRAM SHOWING HOW A RIVER GRADUALLY SHIFTS ITS BED.

a, a, a, The banks against which the current of the stream, shown by the arrows, strikes, whilst a corresponding silting goes on at the opposite points marked *b, b, b*. Where the river, meeting with some obstruction, takes a large sweep and winds back again upon itself, as at the point A, a new channel will in course of time be formed there, the old one at B would be silted up, and the river would occupy somewhat the position indicated by the dotted lines; and so on. (*After B. D. Woodward.*)

Cut-offs.—These conditions are seen to great perfection and on a huge scale in the Mississippi River. From the mouth of the

Ohio to the Gulf of Mexico it is 1,097 miles long, though the distance in a straight line is about 600 miles less, its numerous flexures also reducing the rate of its descent to less than half the inclination of the plain down which it flows. The immense curves of this stream in its course through the soft alluvial plain are such that, after traversing twenty-five or thirty miles, the voyager is brought within a mile or two of the place he had before passed. During heavy floods the water sometimes bursts through these "tongues of land," or peninsulas, forming what are called "cut-offs," which may become new and permanent channels, though the height of the banks and the great depth of the river check the frequent formation of these cut-offs. They have, however, been produced by artificial means, though the attempts at Bayou Sara in 1845, and at Vicksburg in 1862-63, failed. Semi-circular lakes, which are deserted river bends, are scattered all over the alluvial tract of the lower Mississippi. They are haunted by alligators, wild-fowl, and garfish, driven into the secluded places by the steam-boats on the main river. At high water the river flows into these lakes—the Aigues-Mortes or Dead Waters of the French geologists—when the low country around is entirely submerged and looks like some vast lake with wooded islands rising out of the flood. In other cases these "aigues-mortes" get gradually silted up, choked with vegetation, and in time become swamps, or marshy land. The river has more than once by bursting through one of these cut-offs shortened its course by 30 miles, and, by piling up sand-bars and forests in front of them, forced several towns which were formerly on the banks into the country. The village of Delta, built three miles below Vicksburg, is now, by a comparatively recent cut-off, two miles above Vicksburg—a change in the reverse course, which has also shut off both of these places—like Osceola, St. Genevieve, and others—from communication with the river. The boundaries of parishes, counties, and even of States, have in this manner been altered. In the morning a man might go to bed in the State of Mississippi and by dawn find himself and his farm in Louisiana; while, as a well-known American writer facetiously—though not less truthfully—remarks, such a thing happening in the Upper River in former days could (without either the serfs or their master having any voice in the matter), by transferring an estate from Missouri into Illinois, have manumitted the human chattels of a slave-holder. The Missouri, though not quite so wayward, is also rapidly wearing down the bank on its southern mouth, and altering its course accordingly. The rivers of the Punjab act in an almost identical fashion. Not one of them is at any time exactly where it was the year before. The town of Mittan Kót, just before the common confluence of all the rivers, has twice (according to the ordinary way of speaking of it) been "carried away." In reality, though many buildings and much property on the banks of all these rivers are annually swept into the river, this is seldom done without warning. When the people see what is inevitable they move farther back, or to some part of the river side that seems more secure. General Maclagan tells us that when surveying in Upper Sind, and engaged in recovering positions he had mapped the year before, he missed a village that was on his books, and on inquiry it was pointed out to him on the other side of the river. The people, warned of what was coming, had migrated over the water. The river had cut in more than half a mile from its bank of the year before.* Even in the comparatively small rivers of Europe this constant changing of the character of the bed is seen, as the accompanying chart of the Danube at different dates shows (Fig. 155). Something similar, though on a much smaller scale, has more than once happened with the Tweed, which, by altering its course, has transferred portions of a farm from Northumberland into Berwickshire, or, in other words, from England into Scotland.

Our Scottish "holms" and "haughs" are the outcome of their windings in former days,

* "The Rivers of the Punjab" in *Proceedings of the Royal Geographical Society*, 1885, pp. 705–719.

and of the erosion already briefly indicated, for the windings of to-day are often the survival of countless old channels of various dates, which, here and there interlaced and here and there got piled up, the line of least resistance being everywhere that which the river followed in forming, as flood after flood subsided, its permanent channel (Fig. 155).

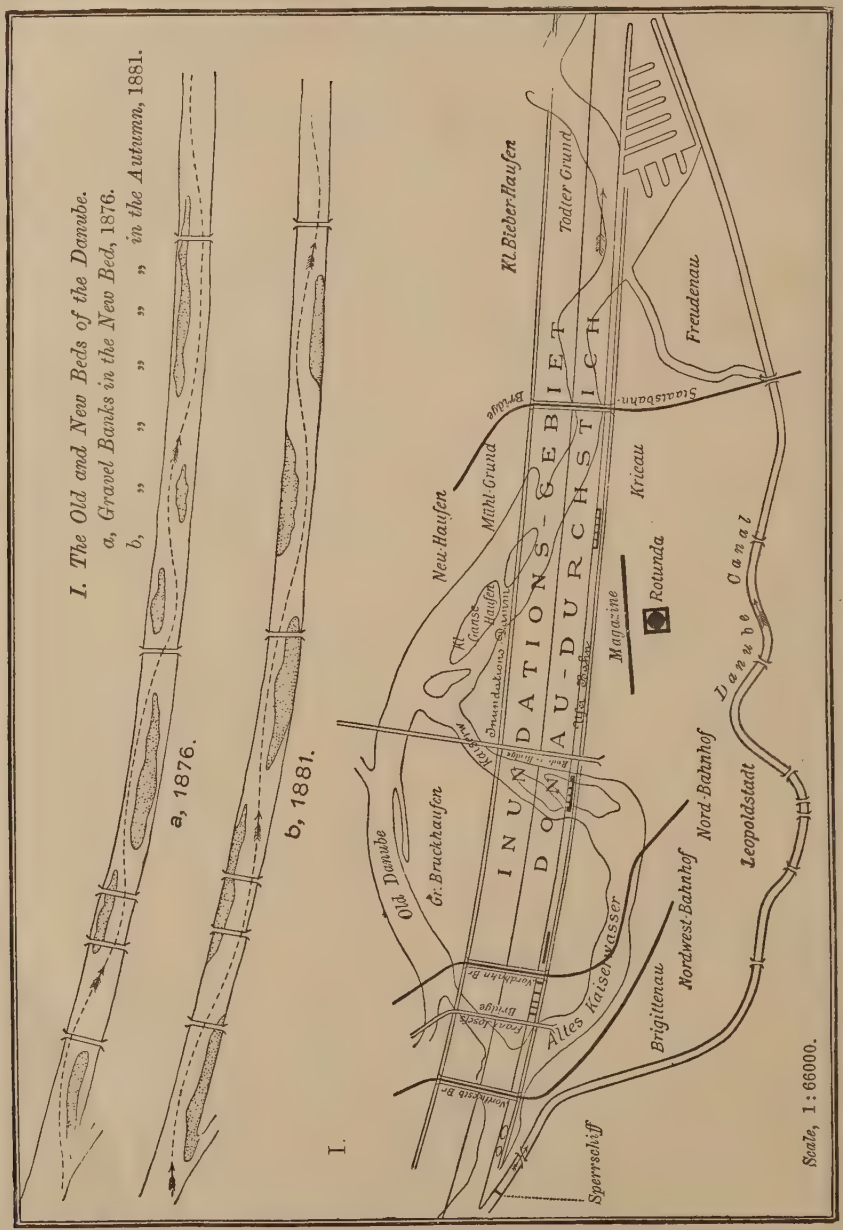


Fig. 155.—THE CHANNEL OF THE DANUBE AT VIENNA, SHOWING THE CHANGES WHICH EROSION CAUSES IN ITS BED.
(After J. Lorenz.)

The classical windings of the Greek Meander, and of Achelous, are of course familiar, while the Tonke of Central South Africa, and the Pimichin of South America, may be instanced as specimens of winding inland rivers.

Twin and Inosculating Rivers, etc.—Some rivers, like the Obi and Yenessei, the Yang-tse-Kiang and the Hoang-ho—*i.e.*, the Hoang-ho as it reached the sea prior to the floods of 1851–3—the Euphrates, the Tigris, the Ganges, and the Brahmapootra, all rise close to each other, and fall into the sea in near vicinity, though in the interval they give each other a wide berth—a fact due chiefly to "accidental" circumstances connected with the contour of the country through which they flow. On the other hand, it is quite common for rivers which rise in close proximity to each other to inosculate—or, as the anatomist terms it when describing this condition of veins, anastomose—before they reach the sea. The Amazon and the Orinoco inosculate by means of the Rio Negro and the Cassiquiare. The very opposite arrangement is found in some of the rivers of North America. The Columbia and the Mackenzie, for example, arise so close together, that they receive tributaries from the opposite ends of the same lake in Athabasca Pass in the Rocky Mountains; yet they flow in such diametrically opposite directions, that they look on the map like a line roughly drawn from the Arctic Ocean to the Pacific. The Tweed and the Clyde, which, during great floods, have been known to inosculate by the inundation of the boggy ground at the Head of Biggar Water, also lie nearly in the same straight line.

Rivers, in the course of the world's history, have entirely altered their course. The *Grande Coulée* of the Columbia River is its old bed, and there has been much discussion over the question whether, during the historical period, the Amú-darya (the Oxus) of Central Asia did not flow to the Caspian instead of to Lake Aral, in an old channel into which the Russian Government intend to divert it. Mr. Stanley also describes several old beds of the Congo running parallel with the present river.

Deflection of Rivers by Rotation of the Earth.—Like the winds, rivers, though more strictly bound to the soil than the atmospheric currents (water being heavier than air, and more sensibly affected by acquired momentum), exhibit a tendency, when flowing in a meridional direction—from northward to southward, or *vice versâ*—at some distance from the Equator, to be deflected from their course by the rotation of the earth on its axis. This phenomenon is, however, much less marked than in winds, which, when they move from polar latitudes—where the velocity due to rotation is small—to more southerly zones—where it is greater—lag behind and get bent more and more to the westward, so that a wind which blew out of the north becomes, as it gets southward, a north-east one, and *vice versâ* on the other side of the Equator, or from the opposite direction. Accordingly, Von Baer maintained that the Siberian rivers which flow Poleward press upon their eastern instead of upon their western banks; the contrary being the case with those whose course is in the opposite direction.

The Irtisch is an example of the one phenomenon, the Volga of the other. The first-named river is said to have so cut into its right bank, that in 240 years one village has been shifted a mile to the eastward, and others driven back by the inroads of the current to an almost equal extent. The bank which these rivers desert is low ground having all the characteristics of an abandoned river-bed, while that upon which they press is comparatively steep and high. To take an example from the American continent, the Mississippi River is slowly moving westward (p. 299). At Hard Times, a village in Louisiana, it is two miles westward of the line it used to take, so that the spot where this settlement formerly stood is not in Louisiana at all, but on the other side of the river in the State of Mississippi. Indeed, it has been affirmed, not without scientific basis for the statement, that the course of the river down which La Salle sailed more than two centuries ago is now dry land. In recent years, among minor incidents of the kind—though the fact has

no direct bearing on the question under discussion—the town of Napoleon, the county seat, has been swallowed up by the Arkansas River, a tributary of the Mississippi, and scores of other places are being gradually shifted back in terror of a like fate befalling them. There is, on the other hand, some ground for believing that the tendency of the Mackenzie, which flows north into the Arctic Ocean, is to abrade its east more than its west bank, though the data on the question are too fragmentary and vague to admit of anything like safe generalisation. The Nile in Egypt also encroaches on its eastern bank and deserts its left; and many geologists believe that at one time the Thames flowed northward from the Hope through Essex, but that, pressing continually on its right bank, it gradually worked its way through the clay ridge which extends to the Stour, leaving extensive marshes on the left. Again, Professor Finger has pointed out that the Danube between Vienna and Belgrad is acting in a fashion very similar to the Volga. At the same time, it requires some faith to believe that the rotation of the earth has much to do with the deflection of river currents and abrasion of river banks. It may influence them, no doubt; though to the more apparent mechanical operations already described, or to be described in the next chapter, the phenomena noted may be more properly ascribed.*

Underground Rivers. — From what has already been said regarding the power of subterranean water to erode rocks into caverns, it is clear that in many places rivers must flow for a considerable distance underground. Springs do so, and between rivers and springs there is really no distinction in kind; there is only one of degree. Some of these large springs or small rivers have already been noted (p. 277). St. Winifred's Well, at Holywell in Flintshire (p. 290), in such local repute for its influence in rheumatism (albeit it has no medicinal qualities whatever), may be regarded as a river which springs full grown out of the ground; and no doubt the fable of

> "Divine Alpheus, who by secret sluice,
> Stole under seas to meet his Arethuse,"

was founded on the mythologist's knowledge of some of these underground passages existing in the limestone regions of Greece; and possibly Coleridge's myth of "Alph the sacred River" in Xanadu, which ran "through caverns measureless to man," was suggested by the same classic tale. However, the Nahr-el-Kelb of Syria—the "Lycus flumen" of the old geographers, which was the origin of so many legends—actually issues, in part at least, from great caverns, the roofs of which are festooned with stalactites. The Stymphalus, for example, disappears in a "katabothra" or chasm towards the edge of the Arcadian table-land, though where it emerges is uncertain. It is, however, certain that twenty miles from this "katabothra" several streams issue low down near the sea level from the rocks of Mount Chaon, and unite to form the Erasinus, the one permanent river of the Argive Plain, which, most probably, is the Stymphalus come to light again. Dr. Clyde, who seems to hold this opinion, notes that Eregli Lake, on the Anatolian table-land north of Taurus, not improbably finds an outlet for its surplus water in the Cydnus, south of Taurus. Another underground stream is the brook which, rising near Hebron, flows by Gerar to the sea, and describes so determinate an underground course that it is tapped at many places for the supply of the villages overhead. Again, the Guadiana, after flowing for thirty miles overhead, vanishes underground, and for the next thirty reappears only at intervals in the shape of lakelets—the "oyos" or eyes of the Guadiana, as they are called. Another good example of underground waters is afforded by the subterranean streams which drain from Lough Mask, in County Galway (Ireland), into Lough Corrib, and are exposed to view at various places in their four-mile course, owing to the subsidence of the limestone through which they have eaten their way (p. 277). An underground river has, however, all the

* Von Baer, in *Bulletin de l'Acad. de St. Pétersbourg*, 1860; Klockmann, in *Jahrbuch Preuss. Geol. Landesant.* 1882 (cited by Geikie in "Text Book," p. 14).

characteristics of one above ground, being big or little according to the amount of water which it receives, and, as that which tumbles through the Peak Cavern in Derbyshire shows, may be a furious torrent fed by tributaries swollen by the heavy rains, which percolate through cracks in the rock.

Taste and Colour of Rivers.—As all water is naturally pure, anything which gives colour to a river must be of extraneous origin, derived from the soil, from the air, or from its tributaries, which again must have obtained the impurity from one or other of these sources. Hence the Salt River of Australia, or the Rio Salado and numerous saltish streams of the Argentine Pampas, must have imbibed their flavour by the feeders washing into them the saline efflorescence found so plentiful on the soil in these regions. The Athabasca receives a saline feeder a little below its confluence with the clear water. It rises in a natural salt spring or lakelet of considerable size, and below Lake Athabasca is a second saline feeder rising in the Cariboo Mountains, which contain vast deposits of rock salt, and, according to the Abbé Petitot, a cavern remarkable for its crystalline concretions.* A "salt river" is also one of the tributaries of the Great Slave River. In like manner the alkali (p. 42), which characterises some of the streams and lakes of Eastern Oregon—the Klamath Lake and its defluents, for example,—is washed out of the earth of the neighbouring country. Water which comes in contact with metallic ores undergoes a total change by admixture with acids, just as mineral and other medicinal springs, for exactly the same reason, are distinguished by various properties, due entirely to the substances which have been dissolved during their passage through the soil or the rocks. The Rio de Vinagre—the "Vinegar River"—of New Granada, in Central America, is sour from the sulphuric acid in its waters. The Orange River, in South Africa—which gives its name to the Republic through which it flows—contains cuprous matter, which renders it poisonous to fishes in part of its course, though its name is in honour of the House of Orange. In Algeria there is a stream inky black, and, indeed, only diluted ink, owing to one of its two tributaries being strongly impregnated with the iron which it imbibes from a ferruginous soil, and the other from meandering through a peat marsh, being equally rich in gallic acid, the two principal ingredients of ink. The ancient Greeks applied the name black to several of their rivers, while the Homeric term—*ἀργυροδίνης*, "silver eddying"—applied to the Peneius, was due to the dirty-white earth of its own banks, and for a similar reason the Achelous is called by the modern Greeks, "Aspropotamo," the White River.† The many Rio Negros and Rio Blancos derive their names from their colour—the hue in the one case being frequently due to the decomposition of vegetable matter, and in the other to earthy sediment in suspension. The Rio Colorado—the Red River—the Hoang-ho, or Yellow River—the White Nile—and the *flavus Tiberis*—the Yellow Tiber—get their designations from a similar reason, though the Niger is not so called because it is black: it is only a corruption of its native name, N-eg-hirrëu, which means "the river."

The *apparent* colour of most rivers is, however, generally due to the bottom or to the banks reflected in its waters, when its current has not, as in so many of the Swiss streams, been rendered turbid from the glacier streams laden with the sediment of the ground-down rocks over which the glacier crawls, or brown, as in the case of the Blackadder in Scotland, from the peat which may have been washed into it. For example, the Guaso N'Erok—*i.e.*, the Black River of Masai Land—owes its name merely to the black volcanic rocks over which it flows.‡ On the other hand, the so-called "blue" and "green" rivers are usually clear waters.

* Sir John Richardson ("Searching Expedition," Vol. I., p. 183) describes a thermal saline spring on the banks of the Mackenzie, with the fissure from which it flows encrusted with crystallised gypsum. Its chief saline ingredient is sulphate of magnesia, or Epsom salts. There are also hot springs at Small Buffalo Creek, on the Athabasca.

† Clyde: *Scottish Geographical Magazine*, Vol. I., p. 93.

‡ Thomson: "Through Masai Land," p. 391.

CHAPTER XVII.

Rivers: Their Action on the Earth's Crust.

Rivers hollow out their Beds—Torrents—Their Geological Import—Examples of their Power—The Great Floods of the Indus—Erosion of Bed by the Detritus which the River bears along—Recession of Waterfalls—Niagara—Lateral Erosion—Examples of Erosion—Cañons—Their Character—Amount of Materials Brought Down—Deltas in Lakes—In Seas—Extent of Some of the Principal Deltas of the Principal Rivers of the World—How they add to Continents—Distance to which Mud can be carried out to Sea—Estimate of the Rate at which Denudation by Rivers is going on, etc.

Rivers, following the law holding good regarding all fluids, naturally flow along the lowest levels to which they can attain. But it is evident, without almost any geological knowledge, that the beds which they occupy, often far below the level of their banks, have been excavated by themselves. The summit of the banks may, for practical purposes, be regarded as the level of the country through which the stream runs, and the distance between this and the bottom of the river the extent to which the current has scooped out the rocks and soil. However, rivers having a tendency not only to dig downwards, but to erode in a lateral direction, it is not always easy to fix upon the original banks of a river, or therefore to reckon in the rough-and-ready way described the extent of its denuding powers; for, as we have seen, the holms and haughs between which it may at present flow have been actually formed of the detritus it has scooped from banks at spots in its upper reaches (p. 298), and not unfrequently the river has gouged out the broad valley, through the bottom of which it flows.

Torrents.—The erosive power of running water is seen in the deep ruts—the "barrancas" of the Spaniards—which heavy "spates" cut in slopes, and in the ravines which score the sides of volcanic cones (pp. 126, 127). If the soil is protected by vegetation, this power is more limited than when the torrents act upon the bare soil, and still more so when the cracks, which form after the earth has been baked by a summer sun, afford an entrance for the gathering rills, which soon broaden them into runnels and channels, and, undermining the sides of the furrows thus widened, play their part in denudation more actively than would otherwise have been possible.

Sometimes torrents work an enormous amount of destruction in a few minutes. In Abyssinia, for example, M. d'Abadie describes a valley as peaceful, and with no sign of trouble brewing in the serene sky, when suddenly "a native, hearing a strange noise at a distance, which quickly increased, would cry out with all his might, 'The torrent!' and, with all haste, clamber up upon the nearest height. Thirty seconds would not have elapsed when the bottom of the valley totally disappeared under a sheet of water, which swept away with it trees, blocks of rocks, and even wild beasts. These torrents, formed in a moment, exhaust themselves in the course of the same day, and leave no trace of their passage but *débris* of all sorts, and pools of muddy water retained here and there in the clefts and hollows." In the Himalayas, the torrents cut gorges through that lofty chain so deep that they admit the passage of currents of warm air from the south, and thereby modify the climate of countries lying to the north of the mountains. About an hour's travel from Thusis, on the Splügen Road in Switzerland, the Nolla once upon a time worked its way quietly through the chasm which it had excavated for itself; but nowadays, owing to the soil being no longer protected by forest, the

rich pastures of the valley have disappeared, and the soil is covered with piles of rock and rubbish swept by the torrents from the moun-

swollen by rain, swept off from the rocks an incredible amount of soil, and converted one of the most beautiful valleys of the Italian

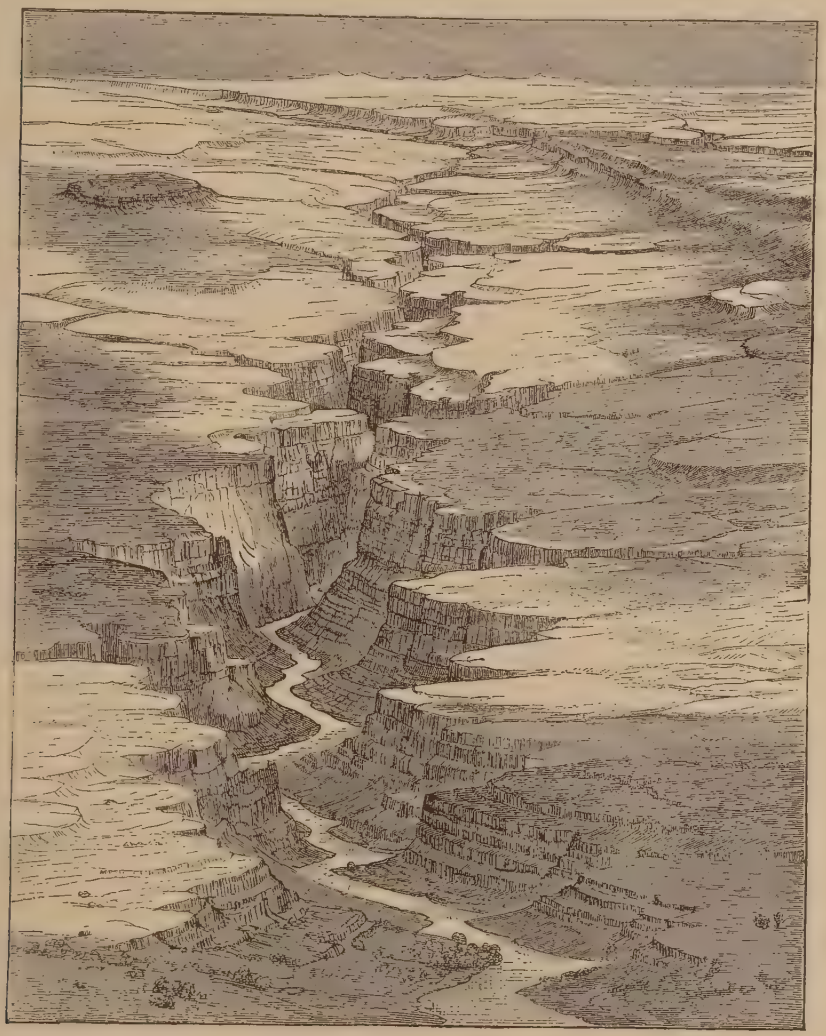


Fig. 156.—BIRD'S-EYE VIEW OF THE MARBLE CAÑON, FROM THE VERMILION CLIFF, NEAR THE MOUTH OF THE PARIA. (*After Major Powell.*)

tain sides. In like manner, the cutting down of the timber converted the Mella, which traverses the district of Brescia, from a river so gentle that Catullus characterised it as the *molle flumen*, into a torrent which, when

Alps into a ravine almost as bare and barren as the most savage gorge of Southern France.* Job, indeed, accurately characterises the action

* Brown : "Reboisement in France," pp. 11, 12 ; "Hydrology of South Africa" (1875) ; etc., etc.

of the torrents, which he must have often witnessed in the Land of Uz, when he exclaims that the mountain is crumbling down, "and the rock is removed from its place; the waters undermine the stones; and by inundations, little by little, the land is laid waste."*

If a temporary barrier is formed in a mountain torrent, the irresistible force with which the pent-up water bursts on the country below when the dam gives way adds a hundred-fold to the eroding power of the stream. Catastrophes of this kind are not uncommon, though in tropical countries they are more marked than in temperate ones, where the distinction between the wet and dry seasons is less marked. The Indus is a river especially subject to floods (p. 297). Between December, 1840, and January, 1841, it was partially dammed by a barrier in the Shayók† tributary. In June it burst, and the collected waters of six months swept down the narrow valley of the Shayók, carrying everything before them. Houses and trees, men and women, horses and oxen, sheep and goats, were borne away at once, and all the alluvial flats in the bed of the river were destroyed in a moment, the flood passing Torbela, a distance of 550 miles, two days later, at the rate of 16·81 feet per second, or 11·4583 miles per hour, being just half that of the flood wave of the Val de Bagnes when it first burst into the valley of the Rhône in 1818. Trees entirely disappeared from the Shayók Valley almost in an instant, and at Kulai, hundreds of miles lower down, about 500 of Rajah Golab Singh's army, who were encamped in the bed of the Indus, were swept to destruction. All the cultivated lands were swept away, and the once fertile Chach was sown with barren sand; though, to make some poor amends, the river sprinkled gold dust over the sterile soil, so that the washings for several successive years were farmed at four times their ordinary rent. Opposite Attock, the waters of the Cabul River were checked and forced backwards for upwards of twenty miles by the mighty waves of the inundation, and the fort of Akora and the village of Messabanda were overthrown, while the back wave of the flood was felt up the comparatively narrow valley of the Indus for ten miles above its junction with the Shayók. Lower down, the loss of property and life was not less than that described. The extent to which the flooded river aided in carrying *débris* was shown by the heaps of stone and gravel all derived from a slate rock, which does not occur at a less distance than eighty miles up. The natives affirm that these travelled heaps were brought down by the great flood on blocks of glacier ice, which got stranded, and, on melting, left the *débris* with which they had been charged.‡

Erosion of Bed.—But though the mere mechanical force of running water will, under circumstances such as those described, hew out deep ravines and sweep vast masses of soil and other terrestrial clothing from the surface of the earth, its most powerful effects are produced by the slow, continuous action of the stream pouring unceasingly over the same surface, or, when it widens instead of deepening its channel, by acting against the banks between which it flows. Then such results as those portrayed in Fig. 3 (p. 9) and Fig. 156 are obtained. The agents at work are the sand, stones, and other *débris* washed by the river out of its banks or from the ground over which it flows in rushing down the steep incline of the early portion of its course. These, ever on the move, wear the bed by their continual attrition. In tumbling upon one another they grind, not only the rocks or other bottom over which they roll, but each other also. Hence the rounded

* This is the literal rendering of Job xiv. 18, 19 in the Vulgate.

† That the flood was due to this barrier has been doubted, since the stoppage was only forty miles from the source of the latter, and could therefore have kept back too little water to cause the great diminution of the stream of the Indus at Attock, 330 miles below, before reaching which the river receives a number of other important tributaries.—Montgomerie, in *Journal of the Asiatic Society of Bengal*, 1860, pp. 128—135. This difference of opinion does not, however, alter the bearing of the above facts regarding the force of the flood.

‡ Shaw: "High Tartary, Yarkand, and Kashgar" (1871), pp. 481—486, where Cunningham's "Ladak" is given as the authority for some of these data.

aspect of river gravel and the constant breakage which goes on by the fragments bumping against one another.

The power of a river to abrade the bed over which it flows varies according to the force of the current, and, consequently, to the size of the eroding tools it can sweep along the bottom. Larger bodies are naturally less easily moved, since their weight, in the language of the geometrician, "increases as the cube of any single dimension, while their surface, which gives a hold to the water, increases only as the square." Hence, making exceptions for rounded bodies, which move more easily than square ones of smaller size, it has been calculated that a speed of 3 inches per second can move river mud, of $7\frac{1}{8}$ per second small gravel, of 1 foot per second common sand, of 2 feet coarse ballast, of 3 feet large shingle, of 4 feet broken stones, and of 6 feet stratified rocks; while a current flowing at the rate of 10 feet per second will dislodge and carry forward pieces of rock as hard and heavy as the igneous ones.

It is easy to see that some rivers are constantly engaged in this work. The Mississippi, for example, is muddy, as are also many of its tributaries; and so turbid with mud are many rivers, like the famous Seboo of Morocco, which has shoaled up the old port of Mehdia, that a glass of it, if left standing for a few hours, will deposit a thick layer of brown sand and clay, leaving the water quite clear. But even the clearest of rivers is engaged in this wearing-away process. If one leans over the side of a boat and watches the bottom attentively, it will be seen that the stream is constantly moving pebbles and sand, though to a casual observer it might appear as if the current did not carry anything along. The river is undermining — "caving in"—the bank, and then carrying forward, in accordance with the law described, the materials which tumble down; or if some stones, pebbles, or sand get into a whirlpool, by being twirled about by the water they form "pot-holes" or deep pits, often of considerable size, in the hard rock of the river bottom (Fig. 160).

Recession of Waterfalls.—Cascades falling over the banks, or waterfalls in the main river, wear deep holes in the bed, into which the avalanche of water tumbles. What is more, such a waterfall will wear back the rock over which it thunders, until, by this recession, the cataract will be miles from the spot where it must have at one time roared. Niagara (Figs. 157, 158) is always cited as a good example of this erosion, the spot where the Falls now are being seven miles from the spot above Queenstown where, it is evident, the water formerly tumbled over the cliff. The rate at which this retrograde excavation is going on has been variously estimated at from one foot to one yard per annum. At the former speed, five thousand years will carry the Horseshoe Fall far higher than Goat Island; and, if this wearing away goes on without stopping, it has been calculated that in time the chasm will reach Lake Erie and lower its level, or that the bed of the Niagara River will be worn into an inclined plane, thus changing the perpendicular fall into a tumultuous rapid. Mr. Woodward, of Washington, is, indeed, inclined to consider that in 2,200 years the Falls will be practically at an end. This is probably a false conclusion, for, as the contour of the Falls, in their present position, is much greater than it could have been at any point below, a much smaller body of water, less effective in force, is consequently passed over any given portion of the precipice, the current being also divided by Goat and Luna Islands. The river bed also increases in width above the Fall until it reaches Grand Island, which divides it into two broad channels, thus greatly diminishing the weight and force of the falling water. From Lewiston upwards the average width of the channel is 1,000 feet. The present curve formed by the Falls and islands is 4,200 feet. Hence the water concentrated in mass and force below the present Falls must have proved vastly more effective in disintegrating and breaking down the shale and limestone than it possibly can be at any point above. After receding half a mile farther, the curve will be more than a mile in

extent, and hold this length for two additional miles, provided the water cover the bed rock from shore to shore.* However, whatever differences of opinion may be entertained regarding the rate and consequences of this recession, the fact of its existing is not and cannot be questioned. Almost every year, in addition to the material worn away by the water, pieces of rock, large and small, give way, and, of course, aid in the excavation described. In 1818, for example, a mass 160 feet long by 60 feet wide, and later in the same year another huge mass, the top of which was estimated at an acre, fell—or equivalent to nearly one foot of the whole surface of the Canadian Fall. In 1829 two other masses, equal to the first that fell in 1818, went down; in 1850 there fell a lump about 50 feet long and 10 feet wide, and in 1852 a triangular mass about 600 feet long and 20 feet wide, while Table Rock, among other similar points, has now almost disappeared, the last fall being in 1886. A recent estimate puts the area of rock worn away at the Horseshoe Falls between the years 1842 and 1875 at 18,500 square feet—equal to 0·425 acre; and between 1875 and 1886 at 60,000 square feet, or 1·37 acre, so that, most probably, it has taken from 60,000 years to 200,000 years, according to various estimates, to cut back the seven miles of chasm which intervene

Fig. 157.—DIAGRAM OF THE FALLS OF NIAGARA.

s, Medina Sandstone; *t*, Clinton Limestone and Shale; *k*, Silurian Limestone.

Fig. 158.—THE FALLS OF NIAGARA.

* Holley: "The Falls of Niagara" (1882), pp. 50, 51.

between the old site of the Falls at Lewiston and Queenstown and the present cataract. It may be added that from Lake Erie to Lake Ontario there is a descent of 336 feet.* These facts are more or less true of every cascade. For instance, since the discovery of St. Anthony's Falls, Minnesota, in 1680, they have receded nearly 910 feet.

Lateral Erosion. — Rivers, however, we have seen, do not always run in a straight course, but whenever the fall is less than about 10 feet in a mile, begin to meander from side to side in the manner and with the results already noted (p. 297), the curve which they make being proportioned to the size of the river. But much will depend upon the hardness and other conditions of the strata through which the river cuts its way, soft beds—as in the Mississippi Valley — giving way more readily before the current than hard ones. Hence, as in the case in question, the valley is very broad, while if the beds are hard, the lateral erosion is much less marked than the vertical. Mr. Tyler considers that the swiftness of a stream increases as the cube root of the volume of water, so long as the slope remains the same, while the wearing-away power of the river increases as the fourth power of its swiftness. Hence, during a flood, which increases the volume of a river twenty-seven times its ordinary amount, the river would flow with three times the velocity and with eighty-one times its former erosive power,† instances of which we have already given (pp. 297, 306).

Even in temperate countries the extent to which rivers wear away the soil is evident to any one who has watched a clear river, like the Tweed, roll seaward during a flood, its waters brown with the sand and clay washed from its banks; though in tropical countries, where sudden floods are the rule, this is much more marked. In reality, the rivers on these occasions are often more mud than water; and in Africa Livingstone speaks of the Zingesi—60 or 70 yards wide and waist-deep —which was made up of as much sand as water. "In most rivers where much wearing is going on, a person diving to the bottom may hear literally thousands of stones knocking against each other." The depth of a valley also affords in almost every case proof of the extraordinary erosive power of rivers. But, though the result is in these instances evident, it is not often that we have an opportunity of seeing for ourselves the extent of this excavating power of running water. There is, however, a well-known case which illustrates this. We refer to the River Simeto, which has cut for itself a passage 50 feet to 60 feet wide, and in some parts 40 feet to 50 feet deep, in a lava dam which, during the eruption of Etna in 1803, was thrown across the channel of the stream. The same form of the erosive power of rivers can be studied in the volcanic region of Auvergne (p. 119), where numerous valleys have been excavated in the outpourings of lava so characteristic of that region; and in the Eifel country (p. 133) the Moselle and its tributary streams have eaten deeply into the ground since they first began to take the courses in which they at present flow.

Another effect of the erosive power of rivers is that not only during their lateral erosion—that is, when they attack the banks—they toss material from side to side (p. 299), but in time they eat through this very material, leaving it in the shape of terraces

* This account of the erosion of the Niagara Gorge is that held by nearly every geologist. However, of late, Dr. Julius Pohlman, Director of the Buffalo Museum, has ventured to doubt the received opinions, and, instead of accepting the hitherto universally-admitted view that the Niagara River originally fell over a hypothetical barrier, stretching from Lewiston Ridge to Queenstown Heights, from which the Falls have, in some 200,000 years, eaten their way back to their present position, contends that the gorge between the present Falls and the Whirlpool is older than the Ice Age. The only part of it he admits to have been excavated by the modern river is the three miles between the Whirlpool and Lewiston. Indeed, it is affirmed that the Falls, instead of cutting their way up the gorge from Lewiston, began as one cataract, not more than a mile or so from their present position. This thesis, though fortified by many facts and much ingenious reasoning, is, however, not sufficiently demonstrated to render the old one, and the data by which it is backed, so obsolete as its learned author would persuade us that it is.

† Jukes-Browne: "Physical Geology," p. 102.

on the sides of the valley, which they have formed. In Fig. 159 this is illustrated. At first the river flowed at the level indicated by the dotted line, *a;* then it worked its way down to the level, *b*, cutting in its course through its old gravel beds, leaving only the patches w w′ on either side of the valley. Still continuing its downward erosion, the levels *c* and *d* were successively reached, and the river cuts its path through hard rocks it is not often that it has all its own way, the river crumbling down the banks, and thus tending to widen the gorge through which the current runs. In a region where little or no rain falls, and which is intersected by large rivers with a swift current, the contrary is the case. The Colorado country in Western America affords excellent examples of this unassisted

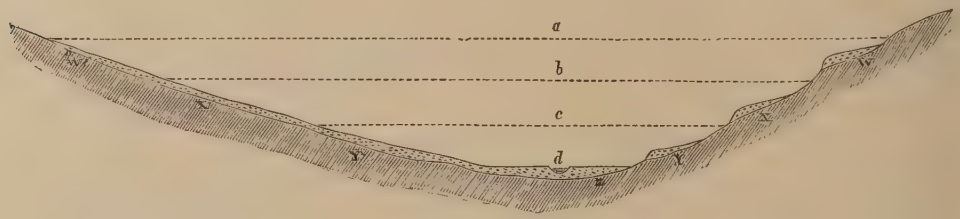


Fig. 159.—DIAGRAMMATIC SECTION OF A RIVER VALLEY, TO SHOW THE FORMATION OF TERRACES OF GRAVEL ON THE SIDES OF THE VALLEY.

same phenomena repeated (x, y). These terraces are, however, not continuous all along the river valley, being thus different from the benches or terraces to which we have already alluded as marking ancient levels during a period when the physical geography of the country was somewhat different (p. 297). Occasionally, too, some of these gravel and sand terraces will merge into each other, and form a continuous layer (w′, x′, y′).* In the flat portions of the Rhine Valley these terraces of clay and gravel are very well marked. But they are also found at a height of from 400 to 800 feet above the present bed of the river, markedly distinguished by their long horizontal ridges from the peaks formed by the Silurian clay slates through which the river cuts its way between Bingen and Bonn. The Dranse terraces of Switzerland may also be mentioned.

Cañons.—River erosion is greatly aided by rain-fall. The rivulets formed by showers cut into the banks form heavy landslips, and in various other ways help to crumble down the sides of a cutting formed by the current of the river down below. Hence most rivers flow in a V-shaped valley, and even when the river erosion. So little rain and dew falls upon the table-lands of this region that the sandy soil is continuously parched by the sun, at a temperature often exceeding 100° in the shade. Hence it is only at the depth of a foot or more that the seed finds the moisture furnished by the melting of the snows—a circumstance which compels the Moqui Indians to deposit the seeds of the maize at that depth below the surface. In this region also are found the deep-river cuttings, or "cañons," which have of late years attracted so much attention (Figs. 3, 156). The rivers have steadily worn their way through horizontal beds of shale, sandstone, and limestone, the eroded edges of which can be seen on the side of the ravines, until, as in the case of the Great Cañon of the Colorado River (Fig. 3), there is a cutting some 300 miles long and about 10 wide, with precipitous sides from 4,000 to 5,000 feet high, and at the bottom of the valley, or glen, another gorge 1,000 feet deeper, through which the river winds like a silver thread. All the endless tributaries of this river have minor cañons, not so deep, but in several instances not less admirable specimens of the peculiar rocky cutting to which this Spanish-American term of cañon has been

* B. B. Woodward: *Science for All*, Vol. II., p. 339.

applied, albeit it is often rather loosely used to designate any river gorge.

But here we may add a word of caution. It must not be supposed that every gorge in which a river flows has been entirely cut by the stream. It may have taken advantage of a pre-existing one, formed during some of those convulsions, which the Uniformitarian will as readily allow as the Catastrophist (p. 118), or have wormed its way in through a fault which in time it has enlarged so as to admit a greater and greater body of water. But in other instances the gorge must have been cut when the contour of the land was different from what it is at present. The course of the River Avon through the Clifton gorge to the sea is a case in point, and the cutting of the River Severn through Wenlock Edge, a lofty ridge of limestone running to the south-west through the heart of Shropshire, is another. If we do not accept some such explanation as that hazarded above, we are driven to conclude—which is of course impossible—that these rivers at one time ran over land of much greater elevation at their mouths than towards their sources. But, as Dr. Callaway has shown, this erosion has been accomplished in a manner perhaps not identically the same in every instance, but very similar, the Avon at Bristol, the Shannon at Limerick, the Hudson at New York, and other rivers having hewn out their gorges when the physical geography of the world was a little different from its present aspect.*

In carrying down the load of sand, gravel, and other stones, the river not only grinds the rocks over which it runs, but when a pebble or other stone gets into an eddy, formed behind a ridge of rock stretching into the stream, it often forms a vertical "pot-hole," or cavity, in the rock (p. 307). These pot-holes are similar to the "moulins," "Strudellöcher," or "Riesentöpfe," of the German, the "Riessenkessel," or "Giant caldrons," of the Scandinavians, which are formed in the rocks over which glaciers move, by the combined action of the water which tumbles through the cracks, or "crevasses," and the twirling of the stones—after the matter of a "quern" or hand-mill—with which it meets. In the Glacier Garden (Gletschergarten) of Lucerne, eighteen of these pot-holes (the largest 28 feet wide and 33 feet deep) form one of the sights of the place (Fig. 160).

A river of very moderate size, constantly shifting from side to side, attacking first one bank and then another, will gradually dig out a valley or bed for itself, seemingly out of all

Fig. 160.—POT-HOLES (STRUDELLÖCHER) IN THE GLACIER GARDEN AT LUCERNE.

* *Science for All*, Vol. II., pp. 162–166, where the subject is specially discussed.

proportion to its size; for there comes a time when the power of vertical erosion is greatly lessened, if not entirely lost. This will happen when the bed of the stream gets ground down so flat that the current has not sufficient impetus, or, as a sailor would say, "purchase," to erode it to any extent. Then it will apply itself to lateral erosion, and, by this means, give itself that meandering course characteristic of the lower stretches of a stream. If, however, the country through which the river flows is elevated in the manner which we have seen is so characteristic of some parts of the world (p. 168), the river will immediately recover its erosive power—the difference between the sea-level and its outfall being altered, the amount of rock and soil to be eroded being proportioned to the elevation of the country through which the eroding river flows. Such an elevation, it is believed, has been at work in the region characterised by the deep cañons already described, this rise being one of the factors which has enabled the rivers to perform such an extraordinary amount of erosion. On the other hand, if the country sinks after the river has ceased to be a vertically erosive power, or, as Major Powell * puts it, has attained its "level of erosion," then the deposition of silt, and so forth, which we shall presently see is among the most important of the geological functions of rivers, will commence long before the stream reaches the sea. Such a river valley will therefore begin to fill up again; indeed, we find many buried river channels considerably below the present level which may be regarded as of this nature.

Amount of Sediment carried down.—All this erosion—this continual wearing away of bottom and bank, this tossing of acres of river shore from one side to the opposite, this removal of islands from one spot and their deposition in another—in brief, the endless pranks which such a river as that of the dimensions of the Mississippi plays—must result in an enormous quantity of sediment of one kind or other being brought down by the river and dropped in various portions of its course where the current is not powerful enough to carry it on; or in the sea, into which eventually the river empties itself. Some of the estimates made as to the extent of this sedimentation have been incidentally noticed (p. 7). The great mud deposits which have been left by the Rhine between Bâle and Bingen show that in one hundred years nearly six feet of deposit have been formed—a measurement which corresponds very fairly with the estimate made regarding the amount of silt brought down by the river. The Thames has been calculated to cast into the sea 1,865,903 cubic feet of sediment every twelve months—a fact which accounts for the constant change which its mouth undergoes, and the formation of fresh mud and sand-banks, rendering charts a year old as obsolete as if they were of the Georgian era. The Obi, Yenessei, and Lena—the three largest rivers of Northern Asia—carry in five hundred years sediment enough to re-constitute 112 cubic miles of land in the Arctic Ocean; while every year the Mississippi tosses into the Gulf of Mexico 3,702,758,400 cubic feet of mud, or, if heaped up in solid form, a mass one square statute mile 268 feet deep. This deposit is washed out of twenty-eight States and Territories—a drainage basin as great as the combined area of France, Spain, Portugal, Germany, Austria, Italy, and Turkey, with the British Islands thrown in. The Ganges deposits in the Gulf of Bengal 6,368,000,000 cubic feet of silt per annum; and the muddy Irawaddy—which, after draining Burmah, falls into the sea by many outlets—cannot be far behind in the amount which it deposits to form the low feverish islands which characterise the mouths of these great Asiatic rivers. The amount of sediment daily carried down by the Danube varies much: on an average it is 67,760,000 cubic feet per annum. The Rhône deposits 38,890,464 tons, or 600,381,800 cubic feet;† and the Elbe, near its point of exit from the

* "Exploration of the Colorado River" (1875), p. 203; Dutton: "Tertiary History of the Grand Cañon of the Colorado" (*United States Geological Survey*, 1882), etc.

† Mellard Reade, in *Proceedings of the Geological Society of Liverpool*, 1882.

Bohemian Basin at Lobositz, carries about 537,325 tons of suspended matter, and about 607,000 tons of dissolved matter.

A section through one of these riverine deposits (Fig. 161) explains the mode in which the strata are laid down, and bears us out in inferring that false-bedded strata (p. 79) were formed in much the same manner; these beds, if deposited in the sea or within the influence of the tide, being alternately fresh water and marine. It must also be remembered, in considering the power of rivers

Fig. 161.—SECTION THROUGH A FLUVIATILE DEPOSIT.

to transport *débris*, that all stones when suspended in water lose one-third of their weight, and that the power of a stream to carry along material increases as the sixth power of the velocity of the current. In other words, double the swiftness of a stream, and you will at the same time increase its motive power sixty-four times, while, if the velocity is trebled, it will be able to move along bodies in its current seven hundred and twenty-nine times more easily than when it was at its normal swiftness.

Deltas. — Such an enormous shifting of material from one part of a catchment basin to another must, of course, have a marked influence on the physical aspects of the regions affected. In that making and re-making of the world which are continually going on, rain and rivers are so constantly grinding down the land, that were not the upheaving forces as regularly at work, the land would in time disappear into the sea. Meantime, the levelling-down process is continuously in operation. If the upper waters of the river lower the upper lands through which it flows, the lower portion of the flood will, by dropping these filched materials in its downward course, raise the bottom of the river nearer its mouth, and the bottom of the sea or of the lake into which it empties. For it may be taken as a rule that, when a river is not utilising the gravel, sand, and mud which it bears down for the erosion of the bottom, it is depositing it in the adjoining region which it floods—as in the inundations of the Nile and the Mississippi—along the banks (p. 298), in the slack water near the mouth, where the current has not power to carry heavy material along, or in the sea, often at a considerable distance from land. In this way the low marshy plains or islands which mark the lower tracts of so many rivers, or between which they creep by many mouths—the Ganges, the Brahmapootra, the Irawaddy, the Mississippi, the Guadalquivir, the Rhine, and the Amazon, for example—to the sea, have been formed, and are still forming. In this manner the Rhône is rapidly filling the Lake of Geneva (p. 7), and in the course of the river and its tributaries many such obliterated lakes may be found. Filled-up lakes are met with abundantly in all mountainous countries, and, among others of the same kind in Great Britain, that which Mr. Browne notices at Rossthwaite, above Borrowdale, may be cited as a good example.

When two mud-laden rivers enter a lake from opposite sides, by their alluvia* joining, the lake may be divided into two. The lakes of Thun and Brienz, near Interlaken, are cases in point. These sheets are separated by a low barrier, two miles wide, known as the "bödeli," which is believed to have been formed in comparatively recent periods by the Lütschine flowing into Brienz, and the Lombach, which now falls into Thun Lake. On the flat ground thus formed, Interlaken ("between the lakes") and several villages are built. Finally, to take an example from North America — the Abbé Petitot tells us that the original mouth of the Athabasca is

* *Alluvium* (Latin, *luere*, to wash, and *ad*, together) is a term applied to material brought together by the action of water. Hence the operation of rivers is described as *alluvial*, and the soil so formed—that, for example, of the river-plains, known in the North as "straths" and "carses," and in the South as "dales" and "holms"—is called *alluvium*. *Diluvium* is, on the other hand, a term confined to the deposits, etc., from extraordinary floods.

now distant a good day's navigation from the Athabasca Lake, into which it falls. Indeed, the river has actually filled up its own ancient estuary with the material it has carried along, just as the Volga detritus is advancing into the Caspian. The deposits, when they fall into a lake or sea, spread out in a somewhat fan-shaped, or rather triangular, form

Fig. 162.—DIAGRAMS SHOWING RIVER DEPOSITS IN A LAKE.

a, River; *b*, Deposits; *c*, Level of the Lake.

(Fig. 162), which, bearing a certain rough resemblance to the Greek letter Δ (delta), has received the name of *Delta*. Such deltas are seen in lakes, as the examples given show (p. 313). But they are still more markedly seen in the comparatively tranquil seas into which the great mud-laden rivers enter, for this, among other reasons, that the largest rivers of the world enter the sea, and lakes soon get filled up by the deltas which form in them. In rougher seas swept by currents, the detritus which the rivers bring down is apt to be swept away before it can form a delta.

Bars, Estuaries, etc.—And here a few words of preliminary observation regarding the outfall of rivers are necessary. Some rivers, like the Tweed, for example, fall directly into the sea; others, like the Severn, the Mersey, the Solway, the Clyde, or the Thames, form estuaries or ever-broadening mouths, which gradually form inlets of the sea, as in the case of the Forth and the Clyde. When a river falls directly into the sea—the Columbia is an apt American example — the downward current being opposed by the waves of the sea and the upward rush of the tide, the place where these contending elements meet is marked by a barrier or *bar* of sand, mud, and gravel stretching across the river's mouth. Indeed, from numerous observations made by Durham and others, it is found that whenever fresh water laden with sediment meets salt water it tends to more speedily deposit its load than it otherwise would have done. Hence, for this, among other reasons, bars and deltas are formed near the mouths of rivers.

An estuary, to use the definition of Dr. Ricketts,* is a bay situated in what has once been "a narrow valley or gorge, and, like a bay, is the result of a subsidence of the land by which the river bed has been depressed below the sea level, so that the waters fill it up, in a similar manner to what occurs if an embankment is constructed across a similar narrow portion of a valley, with the addition of the changes which occur in the level of the water according to the state of the tide." "Lochs," or fjords, we shall see are to a large extent of much the same nature as these firths, and, indeed, between them and the first-named breaks in the coast-line there is really no definable difference, except that the upper portion of a firth usually narrows into an estuary, while a fjord is a narrow glen, at the top of which a stream takes the place of the glacier which once occupied the valley, or which, in some cases—in the Far North—still forms the barrier at its upper extremity. An estuary is kept open by the combined influence of tidal currents and rivers. "During the ascent of the tide a body of fresh water flowing seaward from the higher country is arrested in its course for several hours, and thus a large body of fresh and brackish water is accumulated. Then when the sea ebbs, this is let loose, as in the removal of an artificial sluice or dam. By the force of the returning water, the alluvial sediment, both of the river and the sea, is swept away, and transported to such a distance from the mouth of the estuary

* "On Valleys, Deltas, Bays, and Estuaries" (*Proceedings of the Liverpool Geological Society*, 1871—72).

that a small part only can return with the next tide." *

Backwaters.—A bar will sometimes, when much material is brought down into a stormy sea, spread far from the original mouth of the river, and form a barrier along the coast, inside of which the river may flow for several miles, or may form an extensive lake — like the Italian and Baltic lagoons—before breaking through and entering the open sea. A glance at the map of the American coast from Delaware Bay southward will show how the coast is, as it were, protected by a series of barriers of this character. The " backwaters " of the Malabar coast and other parts of Western India are also cases in point, and the curious breastwork of low islands which are strung along the Dutch, German, and Danish coasts of the German Ocean may, in part at least, be regarded as of the same character, though some of them are remnants of a broken-up piece of the mainland, and others are formed of old deltas.

Extent of Deltas.—Whenever a river is permitted to drop its load of suspended or dissolved sediment, it begins to form a delta, and continues adding to it until the accumulation rises above the water, and the river which forms it flows over the deposits which it has itself laid down. That of the Mississippi is estimated to be about 1,500 feet in depth; a well has been sunk as high up as at New Orleans to a depth of 620 feet without reaching the bottom of the alluvial deposits laid down by the river. The united delta of the Ganges and the Brahmapootra—which covers an area of between 50,000 and 60,000 miles—has been bored through to a depth of 481 feet without the bottom being reached; that of the Po is quite as thick; and the surface of Upper Egypt has been calculated to have been raised by the Nile sediment 6 feet 6 inches since the Christian era.

The deposition of a delta actually blocks up the mouth of a river, so that few of the rivers having great deposits of this kind find their way to the sea through one mouth. The Ganges and the Brahmapootra are examples from Asia, the Mississippi (Fig. 150) from America, the Nile (Fig. 151) from Africa, and the Rhine from Europe, all of which rivers find their way seaward through many comparatively narrow " passes " in the vast delta which have formed around their mouths. The Mississippi—and it is a typical river—narrows as it approaches the sea. At the junction of the Ohio, and for a considerable distance downward, it averages a mile in width. Then its breadth steadily diminishes, until at the " passes " it is little over half that width. Sometimes the delta will take the form of an embankment, between which the river flows in a single stream. In this way the Shat-el-Arab mouth of the Tigris and Euphrates has since the dawn of history added 100 miles to its course. Deltas may even form in rivers far from their mouth by the deposits from their muddy tributaries, as, for example, at the confluence of the Rio Branco with the Rio Negro, in South America. The great plain of Lombardy has been formed by the Po, the united delta of which river and the Adige is 70 miles from Ostiglia to the Adriatic, where it extends for a breadth of 50 miles—the deposits, with those of the Brenta, the Piave, the Tagliamento, and the Isonzo, forming a marshy tract, extending from the Gulf of Trieste nearly to Ravenna. The changes which have been caused by this vast amount of sediment are shown by the fact that the once famous port of Adria—hence the Adriatic—has in less than 1,900 years been silted 20 miles inland, owing to that amount of delta having been formed between it and the sea, where it was situated in the time of Augustus. As for Ravenna, it is now four miles from the sea. The still more famous—indeed the typical—delta of the Nile, the river which, even in the time of Herodotus, was regarded as the bountiful parent of Egypt, has made Memphis—where the sea once reached—a town 100 miles inland, all this great stretch of land being formed for the most part, as Sir Samuel Baker has proved, by the fertilising mud which has been derived from the disintegration of the rocks forming the mountains of Abyssinia, and has been brought down by the Blue Nile and the Atbara during the periodical inundations,

* See also Lyell's " Principles," chap. xxi.; and Greenwood's " Rain and Rivers," p. 107.

and spread over the alluvial plain of the delta. This delta is now 180 miles wide; but, owing to the powerful current which sweeps it, not a great deal has been added to it in the course of the last twenty centuries, though the material which is carried along the coast has helped to obstruct the mouths of Lakes Mariotis, Burlos, and Mensaleh, lagoons formed by some of the Nile mouths in the manner already described (p. 315).

The Mississippi delta has an area of 12,000 square miles, which now forms a vast deposit, filling up what must at one time have been a deep estuary stretching up the Mississippi valley some 50 or 60 miles from the Gulf of Mexico, through which the river at present flows, though beyond the edge of this dry or swampy bed there is still forming a great submarine delta, which will in time appear above the surface of the gulf in the shape of swampy islands, like those bordering each side of the "passes" (Fig. 150).*

The great delta plain of the north-east of China varies in breadth from 150 to 500 miles, and extends for about 700 miles in a southerly direction; yet it is as much the delta of the Yellow River, and to some extent of the Yang-tse-Kiang, as Egypt is the daughter, or, as Herodotus has it, "the gift of the Nile." In this case, however, owing to the absence of currents and to the great quantity of mud brought down by the Yellow River, the delta is rapidly increasing, and the adjoining sea shoaling. The best proof of this is that the town of Pootai, which in the year 220 B.C. was one-third of an English mile west of the sea-shore, was in 1730 43½ miles inland, thus giving a yearly encroachment of about 100 feet. Again, the town of Seen-shway, in the Peiho, was in A.D. 500 on the sea-shore; it is now about eighteen miles inland. In 2,000 years the Yang-tse-Kiang has altered its course nine times, flowing into the sea by as many different beds. In 1851, 1852, and 1853, "the Sorrow of Han," as the Chinese call it, overflowed its banks, submerging a country twelve miles wide, and forcing its waters into the narrow channel of the Ta-tsing River, with the result that it is rapidly eating away its banks, and in time will cause a still greater disaster than that of which it was the cause in the years mentioned.†

The deltas of the Yukon, the Mackenzie, the Orinoco, and other great American rivers, might also be noted, as well as that of the Amazon, which, from shore to shore, including the Para mouth and the island of Joannes, is nearly 200 miles broad, while the vast extent of the deltas formed by the Siberian rivers has already been indicated. The delta of the Indus covers an area of about 3,000 square miles, and can be distinctly traced for a distance of 125 miles along the coast—a dead level throughout its entire extent.

Compared with these gigantic land destroyers and land builders, the little European rivers cannot show any very extensive deltas. Yet some of them are sufficiently interesting. The dreary flats through which the Rhine, so wildly picturesque in its upper reaches, creeps into the German Ocean by a host of bifurcating channels, in which its waters mingle with those of the Sambre, the Meuse, and other Dutch and Belgian rivers, are, however, only a part of its delta: all the "Low Countries" are, more or less, its offspring (p. 7), or the offspring of the Meuse, the Sambre, the Scheldt, and the other streams which now "wander" through it in the manner which Goldsmith's lines so graphically picture. The "Yellow Tiber" is still as yellow with sediment as it was in the days when the Roman poets so designated it, and has been steadily adding to the coast-line near Civita Vecchia some twelve or more feet of silt every year, so that the ancient Ostia—the "mouth," literally—is now no longer deserving of that name, for it is three miles inland. The great delta of the Danube—the joy of engineers and the sorrow of diplomatists, with whom rests the framing of regulations for the navigation of its intricate channels—has advanced into the Black Sea nine or ten miles during the Christian era. The Mediterranean is also affected by the many muddy

* "Countries of the World," Vol. II., p. 103.

† "Countries of the World," Vol. V., p. 26.

rivers which discharge into it, and the Adriatic is filling up with the detritus of the Po and the Adige. The Rhine, in spite of its dropping part of its load in Lake Constance, is every year bringing down much material, though, owing to the strength of the German Ocean, a great deal of this material is swept away and scattered over the ocean, instead of being deposited in a regular delta. Indeed, owing to the embankment of Holland, the real delta is in places below the level of the sea. At Leyden the unimportant arm of the river which retains that name* creeps through the town in a form practically undistinguishable from a canal, and destitute of any current except at low tide, when the sluices at Katwyk are opened. In consequence of a hurricane in A.D. 893, the mouth of the river at Katwyk (the "old Rhine") was so obliterated by sand, that from that period down to 1817 its waters formed a vast swamp, now almost entirely drained. Down to 1840 its overflow waters constituted the Haarlemmer Meer, a lake eighteen miles long and nine in breadth. It may be added that between the Rhine and the Meuse the watershed consists of a low range of sand-hills. The delta at the mouth of the Rhône—though that river clears itself in passing through the Lake of Geneva—has in 800 years been increasing at the rate of more than 9½ feet per annum, so that since the Roman period from 77 to 116 English square miles have been formed. The Po delta advances at the rate of 230 feet a year, and Professor Simony has shown that the Traun is forming a delta in the Lake of Hallstadt, in the Salzkammergut, which in seventy years has increased by 246 feet—a comparison of small things with great which is sufficiently instructive.†

A lake will sometimes fill with singular rapidity. Take, for example, the Lake of Thun, already instanced. In 173 years the Kander delta is affirmed to have encroached on the lake to the extent of 203 acres, now in part covered with trees, though much of it is still in the condition of marshy meadows. The Aar has deposited a fan-shaped delta in the Lake of Brienz nearly 4,000 feet broad. It may be added that the accumulations forming the "bödeli" first descending from the south out of Lauterbrunnen Thal, and then from the north out of the Habkern Thal, are generally cited to account for the curve which the Aar has been compelled to describe. In twenty-seven years the Reuss, on which Lucerne is situated, deposited in the Lake of Lucerne a delta containing, according to Heim, upwards of 141,000,000 cubic feet of sediment, which indicates a deposition at the rate of nearly 19,350 cubic feet *per diem*. And yet the Reuss is, so far as mere size is concerned, an insignificant river.

The Amazon and La Plata, though forming deltas more or less marked, are so powerful in volume that, like the Rhine, they send a great quantity of the mud with which they are charged far out to sea. Sabine fancied that he could detect the discoloured waters of the Amazon 300 miles from its mouth, and it is certain that its current can be felt in the sea at a third of that distance. The fact that the *Challenger* brought up land-derived deposits from 1,500 fathoms several hundreds of miles from the nearest land shows that rivers carry mud far out to sea when the marine currents scatter it over the bottom.

On a smaller scale the same feature of rivers is exhibited in many other parts of the world; indeed, wherever a muddy stream flows with considerable force into a moderately placid sea. Take, for example, the Achelous, which we have already (p. 303) referred to as a river turbid with white mud. It is, as Homer aptly called it, the "king" of the Greek

* The other arm (the Vecht) empties into the Zuiderzee near Muiden.

† Credner: "Die Deltas" (Petermann's *Geographische Mittheilungen*, Ergänzungsheft, No. 56, 1878). An attempt has been made to divide deltas into those which, like the deltas of the Nile, the Orinoco, the Zambesi, the Niger, etc., fall into comparatively deep water (Ausfüllungsdeltas), and those which, like the deltas of the Mississippi, the Ebro, the Lena, the Yang-tse-Kiang, the Hoang-ho, etc., form in shallowish water (Vorgefschobene-deltas), so that the river must find its way through them by many mouths. This classification will, however, not bear analysis. Peat, it is interesting to note, forms in many deltas by the decay of the vegetation on which the river has encroached during its floods.

rivers. Rising more than 90 miles from the sea, away on the confines of Macedonia, the "Aspropotamo" flows in a swift course through some of the wildest, most mountainous, and rainiest parts of Albania, draining, among other classic spots, the western declivities of the Pindus chain before it falls into the Ionian Sea, often a mile and a quarter wide, during the wet season. All along its wild career the river demands its tithe of mud from its banks and bottom, and every runlet formed by the rains, and every tributary turbid with the tribute which is exacted from the mountain side, add to the whiteness of the Achelous, until by the time its course is ended the river is in a position to drop a heavy load into the Mediterranean. This is evidenced by the extensive flat about its mouth, partly pasture land, but chiefly morass and lagoon. Every year the delta is growing, and in historical times has increased so much that, owing to the miles of new land formed, Sir Robert Playfair notes that the whole topography has been altered to such an extent as to make the identification of some important ancient sites a very perplexing task. The turbid water can be seen far from the land, and the Echinades, a group of rocky isles, which rise out of the water, as the name expresses, like the spines on a sea-urchin or echinus, are already more than half surrounded by the deposit. The legend of the contest between Hercules and Achelous refers most likely to attempts made to restrain the inundations of the river within due bounds. In like manner the Wad-el-Kus of Morocco (the Lixus of the ancients) has so altered its estuary in modern times that it is difficult to trace historical spots, far less the garden of Hesperides which Pliny placed here.*

* Tissot: "La Géographie Comparée de la Maurétanie Tingitane," p. 67.

Rate of River Denudation.—The rate at which the denudation is going on can only be estimated vaguely. Dr. Arch. Geikie has endeavoured to do it with more success than any one else. He calculates, for instance, that if a large river like the Mississippi carries off from its basin a mass of sediment which, if uniformly spread out, would amount to $\frac{1}{6000}$ of a foot every year, that is, 1 foot in 6,000 years, Europe (supposing it was worn down uniformly at this rate) would in $3\frac{1}{2}$ millions of years be level with the sea. In valleys and mountain regions denudation is, however, much more rapid than this. The Ganges, it has been estimated, removes one foot of rock from its basin every 2,350 years, and the Po one foot in 729 years. At this rate a valley 1,000 feet deep might be excavated in 1,200,000 years—that is, if the upheaving force were in action all the time.†

All of these facts—and they have only been stated in the barest outline—are of supreme importance, not only in physical geography, but as explanatory of the forces which have been at work in laying down the materials out of which stratified rocks are composed, in arranging or re-arranging the materials of the earth's crust, and in hewing out mountains out of solid land, as many of the Scottish and other hills have been, by a process of "circumdenudation"—that is, scooping out valleys, and leaving the present hills remaining as monuments of the past. For while the "eternal" hills melt away, and the "stable land" vanishes into the waters—

"Still glides the stream, and shall not cease to glide;
The Form remains, the Function never dies."

† Arch. Geikie: "Geographical Evolution" (*Proceedings of the Royal Geographical Society*, 1879, p. 435); Jas. Geikie: "Mountains: their Origin, Growth, and Decay" (*Scottish Geographical Magazine*, 1886, p. 145); etc.

CHAPTER XVIII.

Waterfalls. Lakes: Their Character, Origin, etc.

What Causes Waterfalls—Examples of the Different Kinds and Causes—Lakes and their Varied Origins—Embankments Across Valleys—By Moraines, Eskers, etc.—By Unequal Elevation—By Earthquakes—By Subsidence—Rock Basins hollowed out by Glaciers—Salt Lakes—Examples—Their Characteristics—Examples from Asia and America—Elevated Lakes—The Aralo-Caspian Basin—Oscillations of Lake Level—By Desiccation—The Great Salt Lake of Utah—The Geological Lakes Lahontan and Bonneville—Lake Baikal and its connection with the Caspian—Lake Balkash—Its Decrease—Its Sandy Bed—By "Seiches"—Examples from Switzerland and New South Wales—Temperature of Lakes—Why Lakes are in Elevated Positions in Arid Countries, etc.

Water in its various liquid forms plays so extensive a part in the wasting of the world, that in the brief sketch of geological agents permissible in a work on physical geography only the most striking of them can be described in any detail. However, before touching on the influence of the sea in the formation of scenery, and the remarkable part which water in the form of ice plays in sculpturing the earth, it is necessary to dwell for a little longer on one or two other features of rivers, more especially as they are of importance from a picturesque point of view. Beds of rock, we know already, wear away under the action of the weather or other eroding agents with a rapidity proportioned to their relative hardness. Hence when we find a series of strata of different degrees of hardness sloping in such a direction that they tend to reach the surface, their outcrop will in time develop a series of cliffs or "escarpments," owing to the softer beds mouldering into their component elements long before the harder ones are affected, though, of course, these escarpments will in turn recede, the rocks which give rise to them being in time acted upon by rain, river, and wind, by frost and sun. For a time, however, a river flowing down such a slope will be broken by a succession of waterfalls or cataracts as its current passes from the hard to the soft rocks in its bed, the interval between two cataracts being occupied by a deep pool which the stream has worn in the soft bed. At the same time the main river would receive tributaries, which flowed along the strike of the beds. This illustrates in a broad way the manner in which many waterfalls are formed. But such falls are usually more of the nature of a succession of cataracts or rapids, broken by transverse ridges, than true waterfalls of the striking character of Niagara (Fig. 158); of the Snoqualami, in Washington Territory; or of the three of scarcely less magnitude which—to keep to the United States—break the course of the Snake River in Idaho.

Waterfalls.

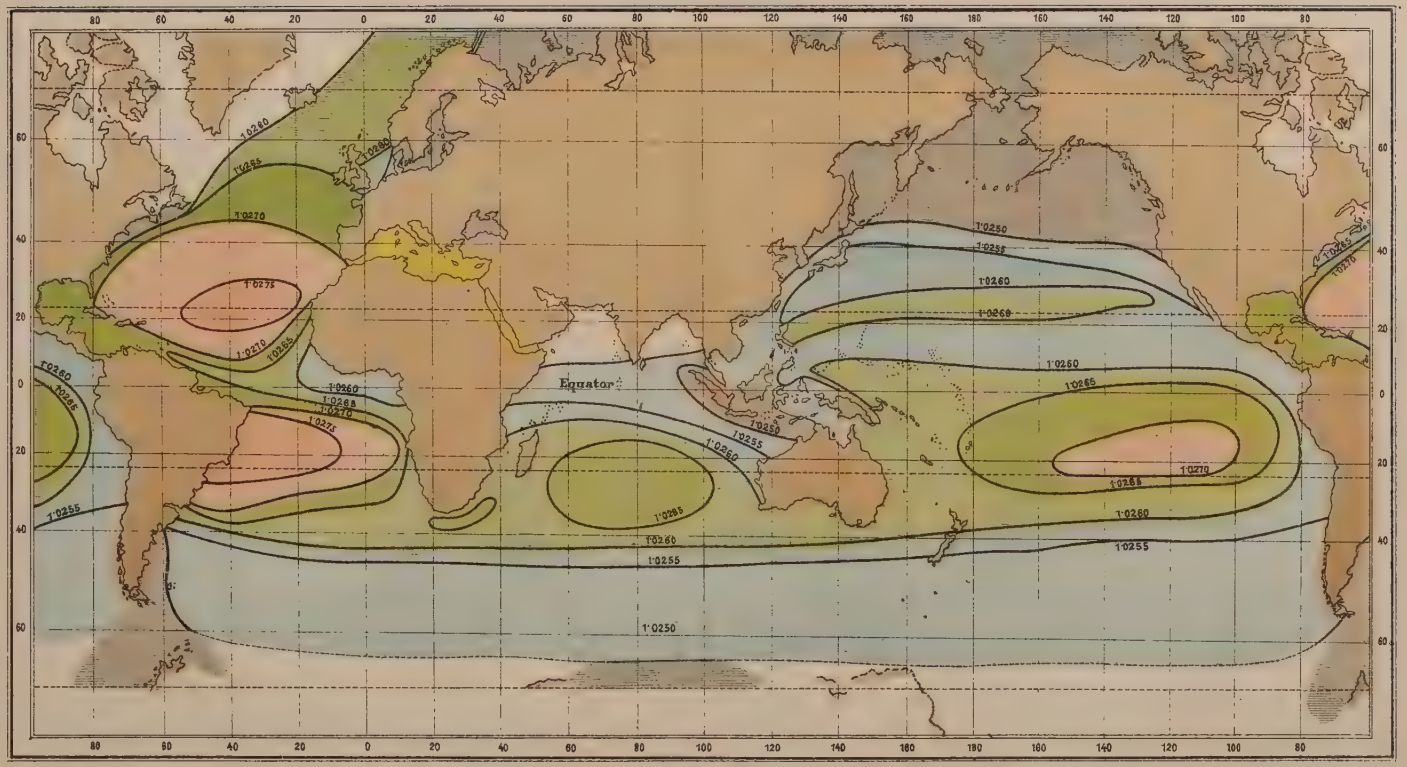
From change of Formation.—In a general way, therefore, a waterfall—not a mere mountain torrent—is caused by an abrupt change in the geological structure of the bed over which a river runs. This may happen, as in the instance already given, when the beds are all on edge, or it may be effected almost as rapidly when the stream flows over the flat beds. Suddenly it changes from a hard to a soft stratum, which it will, of course, erode more rapidly, and every year the erosive power of the stream will increase, owing to the greater impetus which the current derives from falling from a higher and higher elevation from the harder on to the softer rock. It therefore follows, as Mr. Chisholm has pointed out,* that as granite and other hard rocks are found near the surface in those parts of the world in which the deeper layers of the earth's crust have been upheaved in the process of

* "Rapids and Waterfalls," in the *Scottish Geographical Magazine*, Vol. I., pp. 401—422. This paper contains the best scientific digest of this interesting subject.

mountain building, independently of the fact that this process is one which tends to harden rocks that are naturally soft, waterfalls are mostly, though by no means solely, met with in mountainous countries, since here those alternations of hard and soft rock to which they owe their origin are likely to be most frequent. Especially is this true of mountainous regions in which the rivers cut right across the mountains—of those, for example, which intersect the ranges of the Rocky Mountains, and of those which traverse the Alleghanies. This fact again is in South America true of those tributary streams which cross the highlands on the north, east, and west, to join the great rivers of the plains—the Amazon and the Paraguay—and in Africa of the rivers which, in making their way from the interior plateaux to the ocean, have to pierce a barrier of mountains. At the same time, rivers may flow for long distances unimpeded by rapids or falls when they follow the general trend of the mountains. The Amoor, which is navigable for half its length, and the Yang-tse-Kiang and other waterways are even more important cases in point; while the rivers of Southern China, such as the Si-Kiang and the Song-Ka, which have to cross the axis of the mountains, are frequently interrupted by rapids and waterfalls. On the other hand, the tributaries of the east and west rivers, following as they do the trend of the mountains, are unobstructed and often important channels of communication. It also follows that the rivers running across the plains and prairies of America, Asia, and Europe, are seldom, if at all, impeded by the obstacles which are the theme of this section, unless where, as in South America, granite veins cut across their course, or in Europe, where many of the waterfalls are over limestone, gneiss, or granite. The Falls of the Rhine below Schaffhausen, which are the greatest in Europe, are over masses of limestone (the so-called *lächen*), just where the river touches the Jura limestone before re-entering on rocks of Post-Pliocene date, which it had before quitted,* and the rapids between Laufen and Bâle occur where the gneiss of the Black Forest reaches to the Swiss shore of the river. Again, the Danube is constricted within the defile called the Iron Gate, just where the river leaves the Hungarian plain, and passes the crystalline rocks and limestones of the Carpathians, a fact which, though it does not bear directly on the occurrence of waterfalls, is of interest in studying the lateral erosion of streams. All the cataracts—or rapids—of the Nile occur in districts traversed by crystalline rocks; and though the Dnieper, the Dniester, and the Bug, flow through wide plains, the places where the impediments occur is where limestone and granite come to the surface. The Falls of Clyde (Fig. 163), occur in an outlier of Old Red Sandstone, and the great Fall of the Missouri takes place at the point where the red beds of Triassic age pass to those of Jurassic times, while the Falls of Niagara are where the river passes from beds of hard limestone to others of soft shale (Fig. 157). Again, not to enumerate many other cases, Ashgill Force is where the Ashgill, a tributary of the Tyne, falls over a limestone cliff, and has worn a ravine through the rocks below in a manner almost identical with that so familiar in the Niagara. In British Guiana the great Kaieteur Fall is caused by the Potaro River passing from a Sandstone Conglomerate to a softer Sandstone, the cataract being at present 822 feet high.

From Faults.—At the same time, though most falls are due to the causes of which we have supplied some examples, they may, in exceptional instances, be traced to other reasons. For instance, the Glen Falls, near Saratoga on the Hudson, are due to a fault which has raised three sandstone rocks above the level of the three next below them in the bed of the river, though it may be noted that just here the river passes from the Trenton Limestone to the Hudson River group of Shales and thinly-bedded shaly sandstones. The Yosemite Falls in California (p. 88) are also ascribed to a similar cause; though when we know how seldom faults show on the surface, the inequality produced by them being soon smoothed down by the denuding agents so often mentioned, waterfalls which can be

* Meyer: "Physik der Schweiz," p. 334.



DISTRIBUTION OF SALTNESS IN THE OCEAN.

traced to shifting of the strata must be comparatively few, and of short duration, unless the fault or the sinking by an earthquake shock occurs, as in the case noted, where strata of different density meet. In an earthquake country this must sometimes happen. For example, the Sonora earthquake of May, 1887, caused numerous faults and fissures, the entire valley of the San Bernardino being apparently sunk from two to four feet, while the Babispe River and the Yaqui, as well as many minor watercourses, have been affected in a similar fashion (pp. 244-51).*

From Dip, etc.—In the Colorado River, when the strata dip up stream, and the river cuts obliquely across the upturned edges of the formations, with harder rocks above and softer rocks below, Major Powell notes that rapids and falls are all the more certain to occur, and Mr. Chisholm instances one of the same character as occurring on a "gill," just above Ewebank Scar, Kirkby Stephen.†

From Boulders, etc.—It may also happen that, if the river is impeded by loose boulders behind which silt and gravel gather, a waterfall may be formed, and Major Powell notes a case in which the Colorado precipitated itself in a fall of thirty or forty feet over dams of this nature, caused by boulders washed down in a lateral cañon.

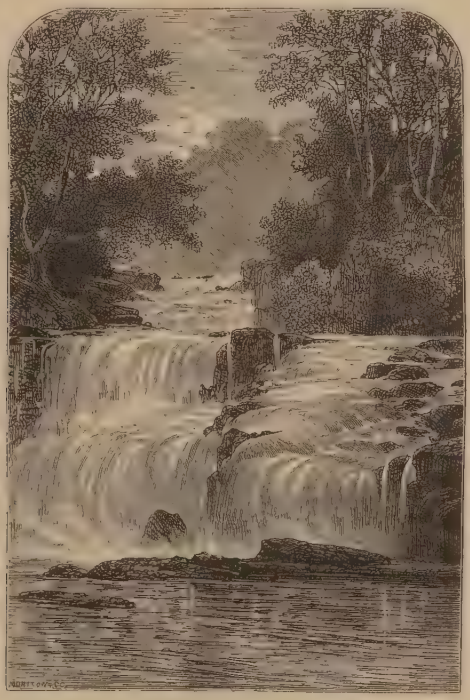


Fig. 163.—FALLS OF CLYDE : CORRA LINN.

From Dykes.—In like manner, when dykes cross the bed of a stream, they will, owing to their material being, as a rule, harder than the

* Goodfellow in *Science*, Vol. X., No. 236, p. 81.

† On the Eden, near the same place, a cataract is formed by some beds of calcareous conglomerate, the pebbles from which assist the river in forming "pot-holes" (p. 311). Small streams sometimes excavate pots eighteen inches deep in eight or nine years.—Brögger and Reusch, *Quarterly Journal Geological Society*, Vol. XXX., p. 750; Seeley's Edition of Phillips' "Manual," p. 157.

strata which they penetrate, and which form the bed of the river, give rise to one or more, or even to a succession of cataracts. Examples of this kind of waterfall may be seen in England in the Lower Red Sandstone at Armathwaite above Carlisle.

Rapids from Islands.—A rapid—that is, a part of the river where the current is much accelerated—may, in some cases, as in the St. Lawrence, between Kingston and Montreal, and in the Yenessei between Vorogovo and Osinovka, be due to the current being interrupted by numerous islands producing a great many channels with conflicting channels. Or a rapid may be caused by the river in passing through a region of hard rock, contracting its bed and "making up for its reduced width by increased depth and velocity." In traversing the Ozark Mountains, the Mississippi passes through such a defile, though there is reason for believing that this defile occupies the site of a waterfall which by the process of recession has been entirely obliterated (p. 307).

From Fissures.—Lastly, the Victoria Falls in the Zambesi (Fig. 164), which fall into a chasm across the river bottom, are due to none of the causes described, but to some volcanic or other terrestrial convulsion by which a rift has been made in the hard basaltic rock which there forms the bed of the Zambesi. The two parts of the bed thus riven asunder show no difference of level. The water simply vanishes down the chasm, and on the opposite side of it grow grass and trees where once the river ran, as Livingstone tells us, on the same level as that part of its bed above the falls. The depth of the chasm is about 360 feet and the breadth between eighty and ninety, and into this gulf the river, a full mile wide, rolls with a deafening roar to escape through an opening situated at right angles to the fissure of the falls not more than twenty or thirty yards wide, from whence it continues its course through a succession of similar narrow chasms, which take the form of a sharply angular zigzag line.* All round this vast cataract columns of steam-like spray rise to such a height as to be visible at a distance of more than twenty miles. This Livingstone attributes to the large volume of air forced into the cleft, owing to the manner in which the water descends, and thus rebounding and rushing up loaded with vapour. It may be added that the lowering of temperature, amounting to as much as $4\frac{1}{2}^{\circ}$, by the side of the Staubbach—"The Dust Stream"—in Switzerland, is ascribed to the loss of heat by the evaporation which is promoted by the finely-divided state of the water when dissipated in the shape of spray.

* Livingstone: "Zambesi," pp. 252-5. For the literature of waterfalls, Mr. Chisholm's paper and Mr. Holley's work (p. 308) may be consulted.

Lakes.

Barrier Lakes, etc.—If an embankment is thrown across the valley through which a stream flows, the dammed-up waters must, if they can find no other outlet, accumulate behind the barrier until a lake forms up to the level of the barrier, when, of course, the surplus flows away in the form of a discharging stream. Thus, a lake of this kind is merely a temporary enlargement of the river's course, the defluent at one end being the continuation of the affluent at the other; the lake between is only a portion of the river enlarged, owing to accidental circumstances. In this way—the lakes of the Columbia, for example—a river may form a chain of lakes united in a series of links by short rivers flowing out of the one into the other. This is the simplest form of these natural features, though perhaps we are not justified in adding, the most frequent. We have seen (p. 281) that landslips and earthquakes (p. 247) very often form more or less temporary lakes of this description. More lasting ones are due to old moraines, that is to say, the earth, stones, and other rubbish which a glacier bears along, and deposits at its terminal end, acting as the dam across the valley through which, in early times, it crawled. These moraine lakes are usually found in the loftier elevations, *e.g.*, in the Innethal above the outflow of the Inn, in the Northern Limestone Alps, at Kusstein, in the Middle Ennsthal, at the outfall near the Gesäuse, in the Pongau where the Salzach

empties, in the Pass of Lueg, in the Drauthal near Lienz, between Spital and Villach, the Savethal near Laibach, and a host of other places in Austria, Tyrol, Switzerland, and elsewhere. Lava streams will also sometimes dam up the rivers across which they run, while those old gravel banks called "Eskers," glaciers, and sand banks, will sometimes play the same part. Beavers also, by forming dams, will often cause lakes to accumulate.

On the other hand, we have seen that old volcanic craters afford space for the accumulation of lakes without any visible outlets (p. 133), and little lakes, or "tarns," are sometimes accumulated in the hollows of the "drift" left from the last Glacial Period. In great lava fields, like those of Iceland, hollows sufficient for the accumulation of considerable sheets of water form (p. 147), and Mr. Green ventures the belief that the remarkable lakes in the Jordan valley (Merom, Galilee, and the Dead Sea) which lie far below the present level of the Mediterranean, have originated in an "unequal elevation of the earth's surface," the land at the lower end of the gorge, through which the river flows, being elevated until a barrier was formed, while higher up the movement gradually changed into one of depression until a considerable part of the valley was sunk deep below the sea-level. But the depression being greater at some spots than at others, profound hollows were formed along the course of the stream now occupied by the lakes in question. In Cheshire, the same excellent geologist notes that lakes have been formed by the dissolving away of the beds of rock-salt which are contained in the New Red Marl. Into the cavities thus formed the overlying rocks sink, and so depressions, soon filled with water, are made on the surface. The lakes which accumulate in the old channels of the Mississippi may also be noted (p. 299), though, as they receive no regular supplies, nor possess any regular outlets, they soon get choked up with herbage, and through the intermediate stage of swamp become moderately dry land. We thus see that valleys become lakes, and lakes may in time return to valleys. For instance, in the outfall of the Zirknitzer See in the Karst, a subterranean channel is so rapidly enlarging that in time the lake will be drained faster than it can fill, and its bed be traversed by a stream running through a deep valley. It may also happen that there are transitions between the one and the other (p. 333).

Glacier Lakes. — The lakes described in the preceding paragraphs, though no doubt the most easily explained, form by no means the most striking of their order, nor, in Northern countries at least, the most common accumulations of water. A more frequent kind are those enclosed in rock basins — hollows surrounded on every side (except when they are broken to admit of the surplus water draining away) by solid rocks, lying in regular beds, as they were originally laid down, and not held back by dams of loose and more or less foreign material. The Cumberland lakes are, for example, lying in hollows of this description. It is therefore clear, unless we can prove that the water is kept in a basin formed by the folding of the strata, that the cavity must have been hollowed out by some other agent than the rivers which have scooped out so many valleys. What then has gouged out the basins of so many of the lakes in the hilly parts of England, Ireland, Scotland, Scandinavia, and North America? The surface has not sunk unequally, for the beds are not parallel to the bottom of the lake, but at all possible angles to it. Accordingly, after exhausting all other methods of explaining their formation, and showing that none could apply, Sir Andrew Ramsay has invoked the aid of ancient glaciers. Ice, when it has entered a hollow, will grind on by the pressure of the mass in its rear until it creeps up hill, and may even, if the slope is not too steep, be forced out again. During the Glacial Period, when the country was covered with ice, this agent must have played an important part in the formation of such cavities. Glaciers cut out the basins they entered into, till, when the great sheets cleared away, such lakes as those of Maggiore, Lugano, Como, Iseo, and Garda, bounded by mountains on the north, west, and east, and by low rock barriers on

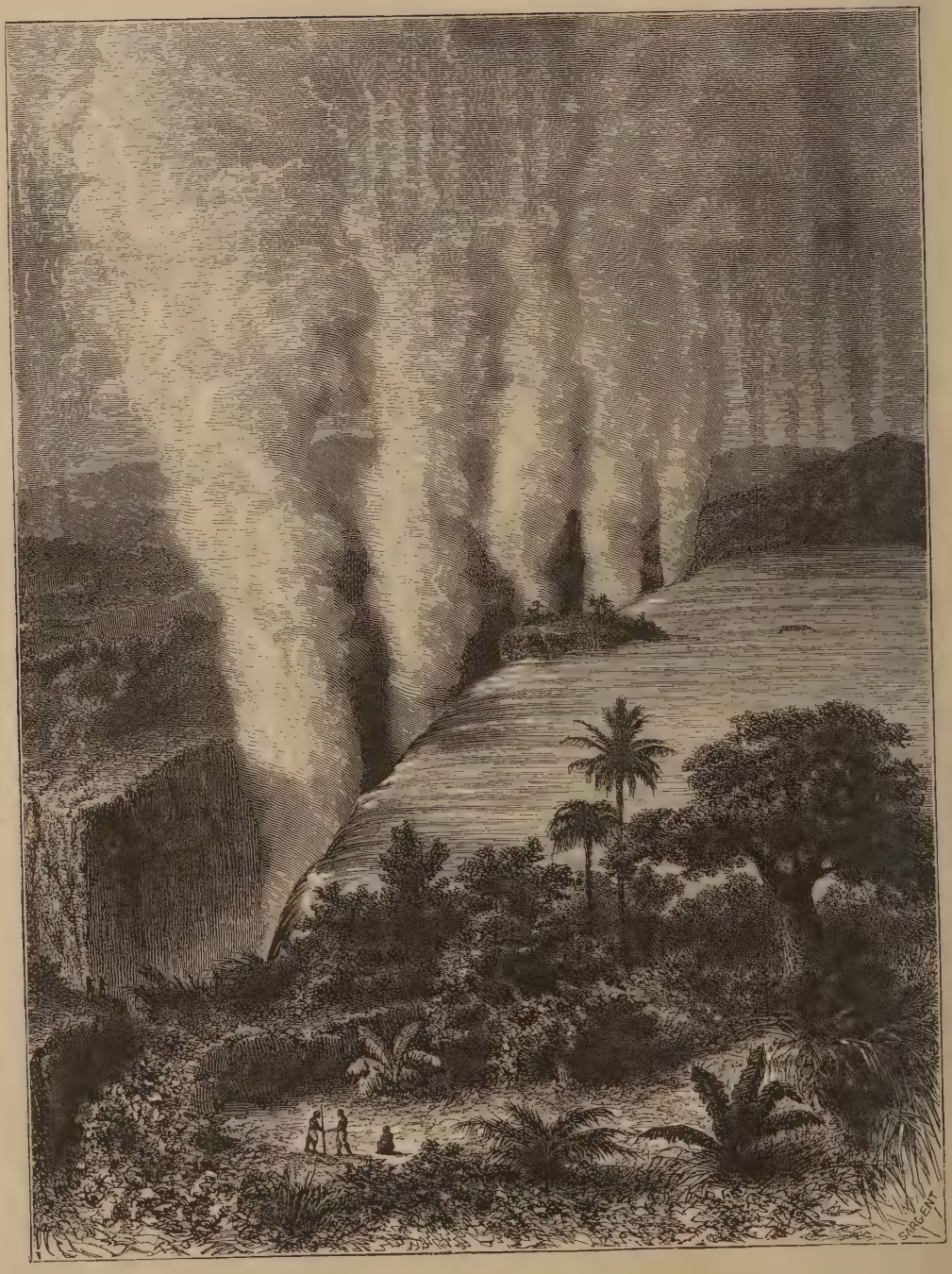


Fig. 164.—THE VICTORIA FALLS, ZAMBESI RIVER.

which the retreating glaciers have dropped moraines on the south, made their appearance. The Lake of Geneva is another example of these glacier-scooped basins. It is about 1,000 ft. deep in the middle, while towards Geneva it gradually shallows, and not far below the outflow of the Rhône solid rocks form the bed of the river only a few feet below the level of the lake's surface. Brienz and Thun, Lucerne, Zug, the Wallen-See, Zürich, Constance, and Neuchâtel, all lie in rock basins of the ice-eroded order; while the Todten-See, Sarnen, Lungern, and many other minor sheets of water, are visibly bordered by glaciated rocks. Most of the Scandinavian lakes are of the same type, while in nearly every part of the Northern Hemisphere where glacial action is evident these ice-scooped lake basins are found. Sir Andrew Ramsay will even class the lakes of Finland among the number, though Baron v. Nordenskjöld avers that they are not rock-bound basins, but basins surrounded by eskers of a gigantic description.* This view, however, is not without its opponents. But the arguments which have been brought against it are feeble compared with those in its favour, so that until a better is formulated, this doctrine—so thoroughly in keeping with all the broad facts of the case—had better be accepted.† Even those who deny the influence of glaciers admit that lakes, like rivers (Fig. 177), often originate from

Fig. 165.—THE DEAD SEA. (*After a Photograph.*)

* Ramsay, *Quarterly Journal of the Geological Society*, 1862, p. 189.

† Professor Heim, who denied that the Swiss or any other large lakes could have such an origin, whilst Professor Penck held the contrary, now admits that the Bavarian lakes are most probably glacial excavations in gravel deposits. On the other hand, Dr. Penck is of opinion that dislocation, in the process of mountain building, had an essential share in the formation of the Lake of Zürich, although ice may have given it the finishing touches. Forel affirms that the Lake of Geneva is nearly divided in two by a great moraine.

streams flowing from under glaciers. But without placing too much weight on this, it must necessarily be true that the causes which operate in the formation of valleys were at work before the process by which the lake basins were hollowed out began. For the movement of a glacier is like that of a river through a valley. It is therefore possible to allow that a valley was formed by dislocation of the strata, and that subsequently the glacier, preceded possibly by a stream, completed its hollowing.

Salt Lakes.—Whether a lake is salt or fresh depends entirely on circumstances. If the amount of water flowing in is equalled by the evaporation from the surface, a lake may receive continual supplies of fresh water and yet maintain its average level without finding any outlet. But in this case it will be salt, or, at least, not fresh, since the river which feeds it carries into its basin the saline materials which they have dissolved out of the soil; and as these solid materials do not disappear in evaporation, they must accumulate in a lake without an affluent. This we see very aptly in the two great lakes fed by the Jordan, in Palestine. The Lake of Tiberias (the Sea of Galilee)* is fresh, because the water which the Jordan pours in at one end is poured out by the same river at the other extremity. On the other hand, the Dead Sea (Figs. 2, 165),† at the farther extremity of the same valley, is naturally salt, because it has no outlet, requiring none since it has no surplus water, the amount which the Jordan pours in being more than drawn off by evaporation. Indeed, the lake is gradually getting smaller, owing to the fact that the supply from the earth is not quite equal to the demands of the sun upon its surface. Hence, also, it must be getting salter, though already the water is intensely bitter and salt, the chlorides of sodium, magnesium, and calcium, being the chief ingredients in it, and its density so great that the human body will not sink in it. This, also, is the cause of the intense salinity of the Great Salt Lake of Utah in North America. Like so many other salt lakes, this sheet was, no doubt, at one time fresh, but by subterranean movements the drainage of a large area of country has been altered until at present the supplies of fresh water which reach it and the evaporation from its surface being about equal, the water has been gradually getting salter. At one time it is thought to have occupied—not the 2,000 square miles of its present area, but a much more extended track, the outlines of which can be traced by the terraces marking its gradually decreasing circumference. This hypothetical lake, to which Mr. Gilbert has applied the name of Bonneville, is thought to have been fully 200 miles long, and about 180 in breadth, to have been fresh and to have drained into the Pacific by the Snake and Columbia Rivers. This period was immediately after an interior basin had been formed by the elevation of the Cascade Range. Lake Lahontan of King was another hypothetical sheet of water dating from the same period. It lay to the westward,‡ and was not much inferior in area to Bonneville. After the meteorological revolution which caused the waters to shrink below the level of their outlet, their salinity began and has increased up to this day, when chloride of sodium forms the chief solid ingredient in the waters of the Great Salt Lake. Lake Lahontan, however, seems to have desiccated entirely before its disappearance: the present lakes of the Great Basin, Pyramid, Winnemucca, &c., are of comparatively recent date, and are nearly fresh, for the reason that the salts deposited when the old lake evaporated were buried or absorbed by the clays and marls that occupy the bottom of the basin. Even now the region occupied by these ancient lakes and their successors is repulsive enough to justify the geological story which attaches to them. The Great Basin stands, in nearly all its scenic features, in marked contrast with the remaining portion of the United States. The open grassy parks and heavily-timbered mountains of the Pacific slope, or the rounded, flowing outlines of the

* 682 feet below the Mediterranean.

† 1,292 feet below the Mediterranean.

‡ It was situated mostly within the area now forming the State of Nevada, while Lake Bonneville embraced almost entirely the present territory of Utah.—Russell's "Geological History of Lake Lahontan." (*United States Geological Survey Monograph*, xi.)

forest-crowned Appalachians disappear, and the scenery suggests nothing of the boundless plains immediately east of the Rocky Mountains, or of the rich savannahs of the Gulf States. It is more like the parched and desert areas of Arabia and the shore of the Dead Sea or the Caspian. It is a region of interior drainage. No stream that runs within it carries its contribution to the ocean; and the climate is so dry that the yearly precipitation does not exceed an average of twelve or fifteen inches. The area thus isolated from oceanic water systems is 800 miles in length from north to south, and nearly 500 miles broad, and contains about 208,500 miles. At the south the valleys of the Great Basin are low-lying, Death Valley and the Colorado Desert being below the level of the sea. But at the north Mr. Russell describes the valleys as having a general elevation of from 4,000 to 5,000 feet, while the intervening mountain ranges rise from 5,000 to 7,000 feet above them, rugged and angular, usually unclothed with vegetation, and marvellously rich in colour owing to the purple trachytes, deep-hued rhyolites, and many-shaded volcanic tuffs, which often rival the brilliant tints of the New England hills in autumn. The valleys or plains separating these mountains are often deserts, totally destitute of water and trees for many days' journey; the grey-green sage brush (*Artemisia*) alone giving character to the landscape. Many of them have at their lowest depression "playas," or simple mud plains, left by the evaporation of former lakes, that must have been in some cases of vast extent, the places which they occupied being now often for hundreds of square miles destitute of anything worthy the name of vegetation. In winter, portions of this area are occupied by shallow lakes, but during the summer months they become so baked and hardened as scarcely to receive the imprint of a horse's hoof, and so sun-cracked as to resemble tesselated pavements of cream-coloured marble. Other portions of the valleys become encrusted to the depth of several inches with "alkali" (p. 42), which rises to the surface as an inflorescence, and takes the appearance of drifting snow. This dry surface material of the desert is sometimes blown about by the wind, saturating the air with alkaline particles, or is caught up by whirlwinds and carried to a great height, forming hollow columns of dust. These swaying and bending columns, sometimes two or three thousand feet high, rising from the plains like pillars of smoke, form a characteristic feature in the desert of the Great Basin.*

Elevated Lakes. — It is therefore evident that the mere fact of a lake being salt is no proof whatever of its having, according to a widespread popular idea, been at any period of its history a portion of the sea. At the same time, there is just as little doubt but that at one time some saline sheets of water in the interior of continents have been part of the ocean. This, we have indicated, does not hold true regarding any portion of the Sahara, and it is more than doubtful whether the Chotts—those marshy lakes in the interior of Tunisia, which lie below the level of the Mediterranean, and which M. de Lesseps proposed to flood—were ever part of that sea. They are rather lakes which, having no outlet, have become salt, and are gradually decreasing or drying up. But if many parts of the Mediterranean, German Ocean, or Baltic, were elevated a few fathoms they would become hill and dale, the dale being, in various cases, closed basins filled with salt lakes. That this has, in more than one instance, been the origin not only of salt- but of fresh-water lakes is rendered probable by a variety of circumstances. The great Russian lakes Ladoga and Onega are, to all intents and purposes, mere prolongations of the Gulf of Finland, leading northward to the White Sea, the intervening land having been converted from a water channel by a very slight elevation of the region in question. Again, many of the Scandinavian lakes could have been portions of the Baltic when the coast was lower than at present, and even now a comparatively slight rise of the land would convert the Baltic into a lake. But in the Northern Hemisphere no sheet of salt water thus enclosed could long remain salt. It must, owing to the wet

* *Science*, Vol. X., Aug. 12, 1887.

character of the climate, be amply fed by streams, and as the evaporation in these very damp parts of the world is comparatively small, the surplus water would find an outlet by means of overflowing rivers. Hence a circulation of fresh water being established through the lake it would speedily lose its original salinity. What is more, in some fresh-water lakes—in North America, for example—marine crustacea still live, having been gradually able to adapt themselves to the altered conditions of life caused by the slow change of the medium in which they exist from salt to fresh water. The same facts hold true regarding some of the Swedish lakes (p. 169). Again, Lake Baikal, a fresh-water sheet, contains a large number of salt-water types of animals, just as Lake Superior does. In the latter case we are justified in concluding that at one time the great North American lakes were portions of the Atlantic, and that in the former instance Baikal was a deep pool of the Caspian. Indeed, the species of animals in the two sheets—the one salt and the other fresh—are identical. Among these animals is, however, a peculiar species of seal *(Phoca sibirica)*, which is different from that in the Caspian *(Phoca caspiaca)*—though the contrary is sometimes affirmed—and many salt-water types of fishes. All over the plains between the Caspian and the Sea of Aral, and between the latter sheet and Lakes Balkash and Baikal, there are deposits of shells, many of which are recent and identical with the mollusca living in the Caspian. Apart therefore from the proofs which we have of elevation and desiccation in that region, these data go far to prove that at one time Central Asia was dotted by sheets of salt water of far greater extent than any of those dwindling marine representatives which remain to this day.

Oscillations of Lake Level.—*Desiccation.*—Vast tracts of Central Asia are covered with drifting sands. In some cases, these sands may be due to causes similar to those which produced the Sahara Desert (p. 8). But in other instances, they are almost certainly the arenaceous bottoms of dried-up salt water lakes (Fig. 166). Prejevalsky, during explorations on the borders of Tibet, found that the western part of the Lob Nor, which has no outlet, was fresh, from which he concluded that it was a reedy sheet of no great depth; but the eastern part of it is salt, all the matter contained and dissolved in the waters of the Tarim being carried into it; and all through this region saline marshes are found, such as those dreary and desolate ones on the plateau of Tsaidam.* Here also the drifting sand and dust accumulate around the shrubs and bushes, and thus in process of time a small hill is formed, on the top of which a new shrub begins to grow. Von Richthofen has shown that these masses formed by the wind are distributed over a wide area in Central and Western Asia, and that the form of the surface of this region is principally due to the action of the wind, rain, and rivers being to a great extent absent, while glaciers could not, except in very high lands, play a very important part in the sculpture of the land. Desiccation is, however, still going on. According to Nikolsky, Lake Balkash is drying up at the rate of over three feet in fourteen or fifteen years. Its evidently detached southern portion, called Ala Kul—now separated from it by sand—is being transformed into a salt pan similar to Kara-Bugaz, the well-known bay on the east side of the Caspian. As the evaporation is very rapid in these regions, and the bays have no tributaries, the loss of water is replaced by the salt water of the lake rushing through the narrow entrance into the bay, the water of which having become concentrated, the salt is continually being precipitated to its bottom. Its north or north-west shore is raised above the lake in a series of terraces covered with a sandy steppe, through which no river runs into the lake, the largest one flowing in this direction, the Tokran or Aitek, being absorbed by the sands before it can reach the beach. The Ayaguz only reaches the lake when flooded. The southern shore has an entirely opposite character, for in many places the change from dry land to water is so

* Salt lakes also abound. In "Countries of the World," Vol. V., p. 105, I have given a view of that of Tsomoriri in Western Tibet.

gradual, that it is difficult to say where the lake begins and the land ends. From the lake nearly to the foot of the mountains

small lakes; and bays on the shores of the Balkash are being turned into lagoons, and then dried up by the action of the sand

Fig. 166.—THE SALT RANGE, INDIA.

stretches a vast waste of sand and sand hills —the former bottom of the lake—bearing no vegetation but "saksaul" and similar shrubs. Ala Kul is now divided into three or four

drifted by the wind.* This fact affords some explanation of the way in which deposits of salt have been formed (pp. 70, 71, 276,

* Schuyler: "Turkistan," Vol. II., pp. 154–155.

277). Some other lakes of Western Siberia and the Aralo-Caspian region are also drying. In the Aral itself the rate of diminution is about 1·8 inch per annum. But Jadrienzew, by comparing Lakes Sunny, Abyshkan, Molokoi, and Chany, in the governments of Tobolsk and Tomsk, as represented in the maps of 1748, 1813—20, 1850—60, and 1880, proves that they are drying up at a much more rapid rate. Lake Abyshkan measured 530 square miles at the beginning of this century: now only three small ponds of one and a half miles in width remain. The same process is going on throughout Western Siberia.*

The mollusca of the Caspian and the Black Sea are in most cases identical, as are also the species in shell banks stranded on the isthmus between the two seas; though the surface of the Caspian is 85½ feet below that of the Black Sea. The slightly saline Sea of Aral—242·7 feet above the Caspian—seems also to have been at one time part of it; its disassociation of this, like the other sheets of water in question, being due to terrestrial movements which have changed the level of the country; though to some degree also owing to the general desiccation. Even the rivers which once fed Lake Balkash have dried up or lose themselves in the sand before reaching its basin, so that its only feeders are from the mountains on its southern aspect.

Salt water lakes show, however, an oscillation of level, whenever the exact balance between evaporation and supply is disturbed. The Great Salt Lake of Utah exhibits this. In 1849, its level was eleven feet lower than in 1877, the rise being attributed to the increased rainfall caused by tree planting, and the greater amount of rain. This, however, was probably a mistake, for from 1866 to the present date the level of the lake has been gradually falling, the water receding from broad flats formerly covered, but now glistening with the saline and other deposits which the lake has left behind.†

Seiches.—This local Swiss term has been employed to designate those vibratory oscillations of level which have been noticed in several Swiss and other lakes. In the Lake of Geneva their range is from three to as much as seven feet. Sometimes the waters will remain for twenty-five minutes or more above their normal level, then descend, and again rise, this vibration being continued for some time. Subterranean movements have been said to be one of the causes of these oscillations; though the general belief seems to be that they are due to atmospheric disturbances, particularly local storms "with a vertical descending movement." The seiches in the Lake of Geneva, as in that of Constance, usually occur at particular spots where the bed of the lake contracts, and are more frequent at night than during the day, and in spring and autumn oftener than in summer, and are most marked when the sun "suddenly begins to shine from amidst heavy clouds." These oscillations are in no way connected with the varying levels of lakes at different periods of the year, those in the Lake of Geneva being connected with the supply of water from melting snow, while the currents, or "ardyres," are due to the rising of subterranean springs. The seiches have been observed in every Swiss lake in which they have been looked for, and in all probability they are to be found in all lakes, and must be ascribed to a variety of causes, though for the present it is idle to affirm that any particular explanation will account for every phenomenon connected with them. Very recently, Mr. Russell has noticed them in Lake George in New South Wales. This sheet is about eighteen miles long, five wide, and fifteen or twenty feet deep. Its oscillations rise from two to six inches, and are of two periods—the longer being two hours and eleven minutes; the shorter one hour and twelve minutes. In most cases the motion is connected with the passage of

* Boas, in *Science*, Vol. IX., No. 210, Feb., 1887, p. 129; Wood, *Journal of the Royal Geographical Society*, 1875, p. 367; and "The Shores of Lake Aral" (1876), pp. 102–146, where the whole questions connected with the Aralo-Caspian basin are fully discussed.

† Jackson: "Les Variations du Grand Lac Salé," *Bulletin de la Soc. de Géographie de Paris*, May, 1880, pp. 417-25.

thunder storms; but at other times it seems to arise from repeated and well-timed impulses of a less apparent form. For example, on one occasion when the lake was very quiet, the water suddenly rose an inch and fell again within thirty minutes, then it arose an inch and a half and fell two inches in three-quarters of an hour; next it rose two inches and fell three and a half inches in one hour; finally it rose three and three-quarter inches in forty minutes, and so started a series of pulsations which settled down to two-hour intervals and lasted twenty hours.

Otherwise, large fresh-water lakes are subject to small variations of level. The supposed exception to the rule is supplied by Lake Tanganyika, in Central Africa, which will often fall two feet in two months, and has been known to fall ten feet in seven months. This is due, however, to the fact that the lake is fed by streams which gather the rainfall of a comparatively small catchment basin, so that in dry seasons the lake, receiving little water from its almost dried-up tributaries, its outlet gets choked by rapid growth of vegetation, so that it is not until the waters of the lake have risen to a considerable level that this dam gets broken down, and the surplus water obtains free course.*

Temperature of Lakes. — Observations made in the Swiss lakes show that after 400 feet have been reached the temperature does not vary much—the bottom, even when it is at 1,000 feet, being only one- or two-tenths of a degree different from what it is 600 feet higher up. In Loch Lomond Christison found a tolerably even temperature of 42° to pervade the water below 500 feet, that is within 100 feet of the bottom, which is not widely different from what holds good of the Swiss lakes at very much higher elevations. For instance, the Lake of Geneva is in autumn 78° at the surface and 41·7° at 950 feet; in February it was 42·1° at the surface and 41·3° at a little over 1,013 feet; while in a host of other lakes the summer temperature at depths varying from 174 to 600 feet runs all the way from 40·8° to 42·0°. In brief, permanent masses of cold water, out of reach of the influence of the sun's rays, seem to lie at the bottom of all, save the shallowest sheets. Hence, lakes equalise the temperature; the mean annual temperature of the Lake of Geneva being at its surface nearly 4° higher than that of the air, and Hildbrandson shows that the great lakes of Sweden exercise an equally important influence on the climate of Scandinavia.

Finally, it may be added, that lakes, from their tendency to get filled up by the rivers feeding them, cannot well be of great geological age. But they are, nevertheless, a true part of the river system, for if they do get obliterated by the agents on which they depend, the river itself tends to disappear, by its bed being choked or altered in the various ways we have already studied.

It may also be noticed that in very hot and dry countries lakes cannot easily exist at a very low level, since the evaporation is so great that in a hot valley, say in Peru or in Nevada, it would soon disappear. But when a high elevation is reached, the climate partakes somewhat of the Northern characteristics. Hence we find Titicaca at 12,500 feet and Koko Nor at 10,500 feet above the sea, while in the Northern Hemisphere many of the principal sheets of fresh water are not elevated more than a few feet above the sea or separated from it by more than a narrow isthmus. †

* Hore: *Journal of the Royal Geographical Society*, 1880, p. 256; and 1882, pp. 1–28.

† Forel, *Arch. de Genève*, 1880; Nichols, *Proceedings Boston Society of Natural History*, 1881; Buchanan, *Nature*, March 6th, 1879; and, above all, an admirable monograph by the same writer in the *Encyclopædia Britannica*, Vol. XIV., pp. 216–21.

CHAPTER XIX.

Valleys and Fjords: their Nature and Origin.

The Shape and Course of Most Valleys dependent on the Rivers which now Flow through them—Exceptional Causes of Valleys—Dried-up Lakes—Earthquakes—Glaciers, etc. Determining Origin of Valleys—Cracks—Joints—Faults—The General Contour of the Country as Influencing the Formation of Catchment Basins—Simple erosive Valleys through more or less horizontal Strata—Transverse and Longitudinal Valleys, across and along the Line of Outcrop of Tilted Beds—Parallel Valleys—Landslips as aiding in the Enlargement of Valleys—Anomalous Valleys—Valleys in curved Beds—Fjords—Their Nature and Origin—Submarine Valleys which were at one time the Beds of Glaciers.

What has already been said on the subject of lake and river erosion renders any lengthened account of valleys and their mode of formation superfluous. For, with few exceptions, all valleys have been eroded by rivers, and most of them are still being hollowed out or rendered broader by the streams which flow through them. Yet this fact, now almost universally recognised, was for a long period not very self-evident to the many writers who have discussed the origin of valleys. It was with them a question whether the rivers had scooped out the hollows in which they run, or whether the drainage of the country had taken advantage of pre-existing hollows. Those who advocated the latter idea contended that in some way the sea had gouged out the valleys, though, as we shall see in the course of the next chapter, the waves can act in no such way, while the ocean below low-water mark has a very slight erosive power. Again, from the fact of valleys often lying between mountains or separating ridges, it was thought that they were due to the convulsions which had led to the upheaval of mountain chasms, or to the contortions which the strata had undergone. On this view the anticlines (p. 74) would be mountains, and the synclines valleys; though when it was evident, as in Wales, that thousands of feet of rock had been removed by denudation since the contortion of the strata took place, the idea that many of the existing systems of minor valleys had been formed either by fractures or by unbroken curvatures of the strata was untenable. *

* Ramsay : *Memoirs of the Geological Survey*, Vol. III., p. 237 ; Rütimeyer : "Thal und Seebildung" (1882).

Exceptional Causes of Valleys.—In reality, though running water, aided by rain and glaciers, has been the prime agent at work in hollowing out valleys, it would be entirely beside the truth to insist that some of the other causes mentioned have not had some part in the business. We know, for example, that valleys may be formed by the depression of the surface by earthquakes; and it is perfectly certain that many of the hollows in the great lava-fields of Iceland and Etna have no connection with rivers or with erosion of any sort. They were formed by the subsidence of the lava streams. Again, there are many round valleys, like the "Parks" and "Holes" of Western America (p. 40), which seem to be the dried-up beds of ancient lakes, and there are plenty of lakes of the present day (p. 323) which, were they emptied by any subterranean movement, or by the outflowing river deepening its own channel to the level of the lake bottom, would become round valleys, which it could not be argued were due to the erosive power of water in any direct form. Take, for example, the Lake of Lüsch, situated on the Heinzenberg, at an elevation of 6,398 feet above the sea. Though fresh, it has no visible outlet, the surplus water oozing away by some hidden channels. But its water softens the porous shale of its banks to the consistency of mud, and large masses of this material are periodically sliding down to the Nolla, which at flood flows into the Rhine in a vast torrent of mud. The lake is therefore actually enlarging by this form of erosion; and the village of Tschappina, which is in part built on a shifting foundation, is known, from some of the buildings having changed their

position, to be in danger from the lake which lies above it. Many valleys also have been the sites of old glaciers, which have been the prime instruments in their excavation, though here, again, the stream which flows under the glacier and washes out the *débris* which the ice has worn off the rock, plays an even more important part in the scooping-out operations than the glacier itself. Indeed, easily attacked by the weather at the point where it is fissured, the rain sweeping over the surface would make the first impression on it along such a crack, and thus form the gentle hollow which determined the future bed of the stream, and consequently of the valley.

A valley may also, for a similar reason, take the line of a fault—not, however, because a

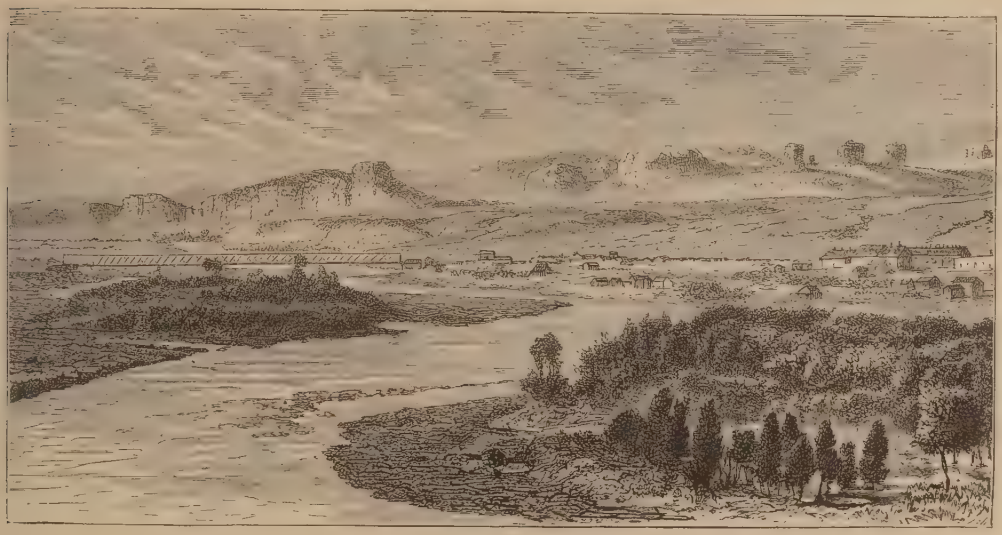


Fig. 167.—VALLEY OF THE GREEN RIVER, A TRIBUTARY OF THE COLORADO.

it quite depends on circumstances whether a valley of this sort will remain a valley, or, by the river flowing through it filling up its deepened centre, become a lake. The two are interchangeable (p. 323).

Determining Origin of Valleys. — While few existing valleys can be altogether attributed to fissures formed in some terrestrial convulsion, it is quite certain that in many cases the cracks which penetrate the strata have had an important share in determining the course which the stream should take, and thereby fixing the line down which the gathering water of the catchment basin should flow. Joints have also had an influence in deciding the line which the river originally adopted, since, naturally, the rock being more fault leaves a gaping fissure into which the drainage flows, for it is extremely rare that a dislocation of the strata leaves any opening on the surface, and even when the uplifted beds rise above the level of the country, the weather and other denuding agents generally efface any signs of the shifting which has gone on below. But there is often along the line of a fault a difference in the mineralogical structure of the disturbed strata, so that erosion has a tendency to take advantage of this fact, as in the small stream flowing southward parallel to the Bala fault, from near the head of Bala Lake to Dolgelly.*

Again, it would be contending in the face

* Ricketts: *Proceedings of the Liverpool Geological Society*, 1872, p. 10.

of the most glaring facts to the contrary to affirm that the initiatory process in the formation of a valley has never been due to a fissure in the earth. Such fissures are among the most frequent concomitants of earthquakes, and when, as in the cases so often cited (pp. 246, 274), the country has been lowered and the drainage disturbed, it can scarcely fail that in some instances at least, the streams will take the direction thus indicated for them.

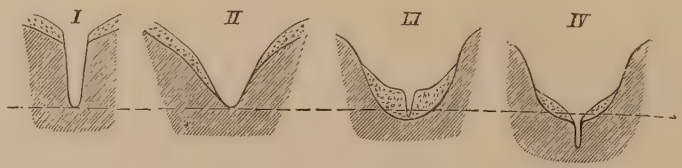


Fig. 168.—DIAGRAMS ILLUSTRATING THE GRADUAL DEEPENING AND WIDENING OF A RIVER VALLEY.

I, Vertical erosion; II, Lateral erosion; III, Formation of terraces; IV, Erosion begun anew.

Finally, it is equally true that the folding and bending of strata have, in some cases, been instrumental in causing hill and dale. But, as we shall presently see, this arrangement of the beds is favourable mainly in so far that it enables the weather and the streams to remove the beds, or not to remove them. In the one case there is a valley, in the other a hill is the result.

No doubt also—indeed, the postulate is self-evident—the contour of the country, when it emerged from under the water, had a primary influence in determining the great watersheds and the course which the drainage of the catchment basins should take. But the secondary valleys, and valleys as they at present exist, are, ninety-nine cases out of a hundred, the outcome of the erosive action of running water; and the various shapes of the valley, and its different appearance in different parts of its course—upper, middle, and lower—depend first on the force of the current in these reaches, and, secondly, on the hardness or softness of the strata through which it cuts its way (Fig. 170).

Simple Erosion Valleys. — The simplest form of valley is, of course, that of the Mississippi or of the great South American rivers which flow from the eastern slope of the Andes through soft alluvial plains to the Atlantic. Where the river must work its way through strata of varying hardness it will be broadly V-shaped, the soft clay or other beds on the surface crumbling down by the rain, while the river at the bottom is contracted within narrower limits. If it flow through a dry elevated district like that drained by the Colorado and the Green Rivers, deep cuttings, separated by flat "mesas," or table-like plateaux, will characterise it (Fig. 167). As for the occasional gorges in the course of a river where the current forces itself through hard rocks, these will often be found to have been caused by a waterfall gradually cutting its way back, as the Niagara and the Minnesota, at Minneapolis (pp. 308, 309), are doing. We see this recession of waterfalls in nearly every place where they are found. In addition to the examples just quoted, the insatiable appetite of the river is exhibited in the numerous falls of the Giessbach and at other places in Switzerland, such as at the Falls of Schaffhausen, where the same action is hard at work. The gorge of the Rhine, between Bingen and Rolandseck, is considered to have been cut by an ancient waterfall, which disappeared long before the dawn of history. But it has left behind it traces of its existence in the gorge in question, and in the little places which, before the river and its tributaries were lowered and the sheets of water in its course drained, were the beds of lakes like those of the Upper Columbia.* Some of these facts connected with the gradual deepening and widening of river valleys by erosion, as shown in the annexed diagrams (Figs. 168–170), might

* Ramsay: *Quarterly Journal of the Geological Society*, Vol. XXX., p. 81.

be suitably studied in connection with the facts regarding river erosion so fully described in a previous chapter (pp. 304—318).

Transverse and Longitudinal Valleys. — Hitherto we have been considering valleys formed in strata, more or less horizontal.

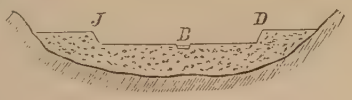


Fig. 169.—DIAGRAM OF A RIVER BED.

B, River bed; J—D, Terraces indicating the former level of the river.

When they are tilted other forms of valleys make their appearance. For instance, when the river runs across their outcrop (p. 77) we have what are known as *Transverse Valleys*, while the tributaries which run along the outcrop of the more easily denuded beds, or, in other words, *follow* the strike (the main one running in the direction of the

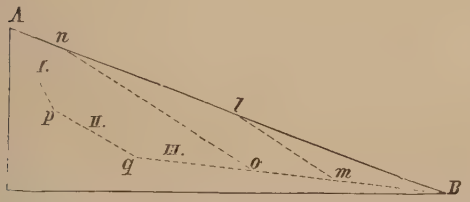


Fig. 170.—DIAGRAM ILLUSTRATING THE SCOOPING OUT OF A VALLEY.

A B, The original slope of the ground; I. *p*, II. *q*, and III. B, The first, second, and third divisions of a river, namely, the mountain, valley, and plain stretches; *l m* and *n o*, The successive erosions of the stream converting the valley from a V-form in its upper course to a U-form in its lower reaches when the river attacks the banks instead of eroding its bed.

dip), are known as *Longitudinal Valleys*, or "Combenthäler," as they are called in the Swiss Jura* (Fig. 173). When the strata are tilted much, it is not uncommon, if the soft strata are divided by considerable thickness of harder beds, for several longitudinal valleys to lie parallel to each other, the valleys being excavated in the soft beds and separated by ridges of uneroded rock. Example of such a valley is afforded by Holmedale, which is scooped out of the soft Gault, which lies between the chalk range of the North Downs and the parallel ridge of Lower Greensand, which stretches from Guildford East close by Leith Hill. Another such valley is excavated in the Weald Clay, which lies between the Lower Greensand and the parallel range of the Tunbridge Wells Sand, while a third valley is excavated parallel to the others between the Tunbridge Wells Sand and the Ashdown Sand, which forms the central boss or saddle of the Weald anticlinal fold. This series of valleys is repeated with a repetition of the strata southward between the Ashdown Sand and the English Channel; so that in the little area of the Weald of Kent, Surrey, and Sussex, there is a system of six parallel valleys which run eastward to the sea. The whole geological structure of the island offers examples of the same phenomena.†

Landslips will often enlarge a valley (p. 283), so that it is not always safe to regard the stream which flows at the bottom as the sole agent at work in broadening the hollow through which it courses. Indeed, we have already seen that the first agent which does so is the stream trickling over the banks, and the rainfall which crumbles down the walls of the trench which the river has begun to dig. This widening of the banks is therefore not quite identical with the landslips which go on, though, in the end, the result is much the same. A landslip may even alter the watershed (Figs. 171, 172). A close examination of any country will constantly reveal the existence of old valley systems—not

* These, however, must not be confounded with the miniature valleys formed by the little streams cutting through cliffs to the sea, which in the Isle of Wight are called "Chines;" in Devonshire, "Coombs;" in Hampshire, "Bunnys;" and on the Scottish borders, "Denes." Geographers, it ought also to be noted, often use the terms longitudinal and transverse with reference to valleys in a looser sense than do geologists. In the Alps, for example, the valleys which—like the great depressions along which the Rhône, Aar, Rhine, and Inn run—take the line of the central axis, are described as longitudinal. On the other hand the valleys of the Reuss, Ticino, Toccia, Adda, and Adige, which run at right angles to it, are termed transverse. But as happens in the upper and lower valleys of the Adige and other rivers, the same valley may in one part of its course be longitudinal and in another transverse, or actually become confluent or undistinguishable, so that the terms primary and secondary, also applied to them, are not strictly definable.

† Seeley's edition of Phillips' "Manual," p. 139.

merely buried valleys, of which we shall presently have to speak (p. 343), which in no way correspond with the present ones. Those are "dead" valleys which, having served their purpose, their rivers have left them and sought other beds, not available at the period when they first began their course. On the other hand, it can be shown that the present river beds are made up of valleys which in one part are very old, in others not so ancient, the imposing Limestone and Dolomite cliffs of the "Gesäuse" between Admont and Hieflau, a comparatively young breach of the Enns, which at a former period had, after passing Admont, made use of the Buchauer saddle and the valley of St. Gallen to reach the north-western direction at Altenmarkt, its present transverse valley, may be cited as another example of the same phenomenon in valley formation. If we follow

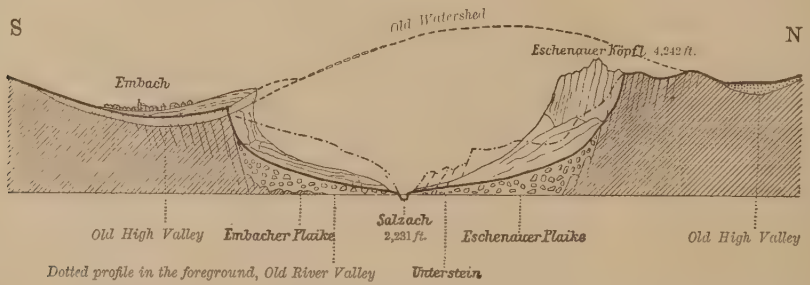


Fig. 171.—PROFILE OF THE OLD WATERSHED AND LANDSLIPS BETWEEN THE PINZGAU AND PONGAU, IN THE EASTERN ALPS.

and in another section still younger, this valley system having been formed at the expense of pre-existing ones. A good example of this is afforded by a well-known region of the Austrian Alps (Fig. 171). Among valleys comparatively young and unfinished is that of the Salzach between Taxenbach and Schwarzach, or, in other words, between the Pinzgau and the Pongau. Before the last piece of the old watershed was broken through above Lend, in the neighbourhood of the Unterstein Tunnel, so well known in connection with the landslip of 1875, the waters of the Pinzgau, as far as the Rauriser Ache, had their outlet through the transverse valley at Zell-am-See, in the section watered by the Saalach. The great landslip in the valley at Unterstein, the so-called Eschenauer, and Trattenbacher "Plaike," on the left bank of the Salzach, and the Embacher and Pfarrwald "Plaike," on the right bank, which took place last century, and the *débris* of which forced the river several miles back to the upper part of the valley, is proof of the continual progress of valley making. Likewise (Fig. 172) on the valley formation still farther back, then it appears, from the high-level river deposits on both sides of the present course of the Salzach between Taxenbach and St. Johann, as also from the present watershed between the Salzach and Enns at Wagrein above St. Johann, that before the transverse valley at Zell-am-See, the Lueg Pass and the valley at St. Gallen were formed, and before the lakes in the Pinzgau and Pongau were in existence, one powerful stream—most likely, Dr. Löwl thinks, during the Tertiary period—ran at a higher level than the present into a bye valley. This valley is indicated by the structure of the Eastern Alps, from the Pinzgau into the Pongau, and the Wagrein district. The stream which flowed through it emptied itself into the high Enns Valley, and then ran through the wide Rottenmann glen into the Mur district. In some of the tributary valleys the eroding action of their streams has not been able to keep pace with the same action in the principal one, for they open up high above the latter and send their water down as waterfalls into its bed. This holds true of

all the more southern side-valleys of the Salzach between St. Johann and the Pinzgau.

Anomalous Valleys.—In the preceding remarks we have, for the sake of clearness, confined ourselves to what generally obtains in valley-making. However, in studying them more closely we find various apparent exceptions, and not infrequently valleys in which follow that valleys which owe their primary existence to joints and faults, may take a course which has no relation to the lie of the strata in which they are excavated, and that many other accidental causes may, in the course of the long period during which they have been working, have interfered with the broad laws which we have thus briefly indi-

Fig. 172.—THE VALLEY OF SALZACH AND ENNS, IN THE EASTERN ALPS.

Old Tertiary longitudinal valley along the Greywacke (Silurian, etc. *a.*) Zone A B.

Old deserted river-course; *a*, near Zell-am-See; *b*, near Wagrein; *c*, near St. Gallen; *d*, near Rottenmann.

Most recent outbreak; *a*, an old watershed between the Pinzgau and the Pongau; *β* The Gesäuse.

several of the causes described have been at work. This is only what might have been expected, when we remember how constantly the contour of the land has been changed by earthquakes, by the slow secular rise and fall, and by the operations of denudation, and how prone Nature is to employ many agents in the earth-sculpture by which her features are formed.

For example, it is not uncommon to see a valley which, for a certain portion of its course, is longitudinal, suddenly turn on itself at right angles and become a transverse one, running across the outcrop of the beds. But in this case a closer examination will generally discover that the transverse valley has at one time been the main one, though at a later date the longitudinal valley, by the increase of the drainage finding an outlet through it, has become the principal one.* It must also

* Jukes: *Quarterly Journal of the Geological Society*, Vol. XVIII., p. 378; Green: "Geology," p. 425, Fig. 112.

cated as holding true in the great majority of cases.

It also sometimes happens that we do not find the principal rivers of a country flowing in the broad valleys between parallel ranges of hills, though it would be natural to expect them to do so, after the rule which it has already been seen holds true in many other cases. On the contrary, they cut right across the ridges in narrow gorge-like valleys, into which the tributary streams which drain through the broader valleys empty. In other words, as Professor Green puts it, the principal drainage is transverse, and the tributary stream longitudinal. Such a case is afforded by the Witham, the Welland, the Nen, and the Great Ouse. They arise in the plain to the west of the Oolite range (hard limestones) which extends from Gloucestershire to Lincolnshire, and, cutting in succession across the ridge, discharge into the Wash. Again, not to

enumerate other instances, the Cherwell—as it is called above Oxford, though it takes the name of the Thames below that city—cuts through the Oolitic range, courses over the flat between it and the Chalk range (which stretches from Dorsetshire to the coast of Norfolk), and trenches the latter at about right angles to its general trend.

In these cases, and others like them, there is no reason for asserting that the gaps through which the river flows were valleys made by some convulsion which rove the hills asunder, or that they were cut in any other way than by the erosion of the rivers which now occupy them. The only explanation, therefore, is to suppose that when these rivers began to run the contour of the country was different from what it is at present, otherwise its course must necessarily have been deflected when it reached the ridge it now cuts across. At the time when the rivers first began to flow, the country through which they ran was "a plain as high or somewhat higher than the top of the ridge." But as the river began to cut its trench across the plain, "atmospheric denudation was at work wearing down the country on either side, the stream carrying away the waste as fast as it was washed in." This explanation, which is given in the words of the eminent geologist just quoted, is quite in accordance with all the facts of the case, and is confirmed by other data which might be cited from many parts of the world. Scotland furnishes numerous examples of mountains hewn out of plateaux, and of valleys formed in their vicinity by the action of denudation,* and in Ireland many rivers, like the Blackwater, furnish instances of the phenomena just noticed. It may even be possible that in some instances the river which trenches a mountain range may in the upper part of its course be older than the ridge which it cuts across, having taken its origin in dry land before the rocks of which the ridge is composed were deposited in the sea or other sheet of water. Then as the chain was being slowly raised the river continued its course athwart the newly-formed land, so that its erosion of the trough through which it flows was synchronous with the elevation of the ridge. In this way Dr. Tietze accounts for the transverse valleys which cut across some of the highest spurs of the Elburz mountains in Persia, and would go so far as to attribute the valleys through which the Indus and the Brahmapootra cross the Himalayas to a similar course of action on the part of those great rivers. This would, however, infer such a prodigiously long life for a river, and its life moreover in exactly the same course during a period when the contour of the country must have altered considerably, and many causes calculated to deflect its drainage have been at work, that one hesitates to at once accept a theory so sweeping. Yet it must be remembered that the Karakoram and Kuenlun ranges, on the slopes of which these rivers rise, are both older than the Himalayas, and therefore must have given rise to a vast drainage before the latter had appeared above the waste of waters. And here it is not irrelevant to remark that the height of any hill is no criterion of its age. The case just quoted is an ample proof of this, and the Scottish mountains, low though they are, were shaved by denudation long before the Alps arose, while the hills of Brazil are much older than the Andes, which in their

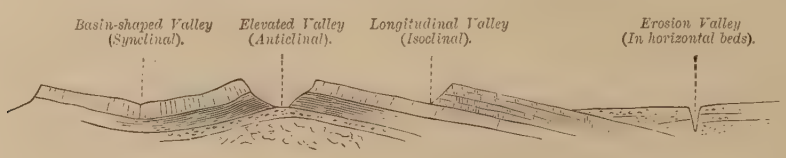


Fig. 173.—DIAGRAM ILLUSTRATIVE OF VARIOUS FORMS OF VALLEYS.

* Arch. Geikie, "Scenery of Scotland" (1887); Jas. Geikie: *Scottish Geographical Magazine*, Vol. II., pp. 153–162, etc.

turn have been worn down by denudation from an average height of 30,000 to that of 12,000 feet.* Supposing, as in Fig. 174, that there are two streams (p' q' and p q) flowing down the opposite sides of a narrow watershed, the steady erosion of the valleys will in time attack the summit where the two streams

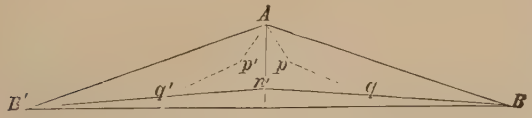


Fig. 174.—DIAGRAM ILLUSTRATING THE MODE IN WHICH WATERSHEDS ARE WORN DOWN.

rise, forming a low "col" or "pass" between them. By-and-by, if the streams are permitted to act, they will wear down the pass until both valleys are joined, and in place of the lofty ridge A, a scarcely recognisable watershed n separates the valleys n B′ and n B′.

form of a series of waves—sometimes fractured by deep transverse gorges or "cluses" at right angles to the direction of the chain. In some parts of Western America this mode of valley and mountain formation is exhibited on a large scale. But in countries which, like ours, have been subjected to much denudation since the hills were formed, the valleys are not, as a rule, in the synclines, nor the ridges separating formed by the anticlines, which is the very opposite of what might have been expected. This peculiarity is, however, due to the fact that strata, after being violently bent and broken, are weak. But their weakest part is on the ridges, and their most compacted part is in the hollows where they have been compressed, or, at least, not exposed to such tension as on the anticlinals. (See also Fig. 35, p. 75.)†

Hence, the one have in the majority of cases remained as hills, while the other have been

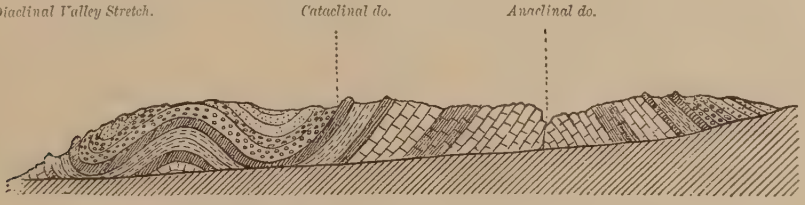


Fig. 175.—VALLEYS IN CURVED AND DISLOCATED STRATA.

Finally, either by erosion or by landslips, such as that of the region shown in Figs. 171 and 172, or which have given the Matterhorn its peculiar shape (Fig. 176), the once separate valleys and streams will be one.

Valleys in Curved Beds.—At the outset it might be supposed that when beds are contorted in the way we have seen them so frequently, the concavities would form valleys, and the convexities hills. But this is very seldom the case. We see it, however, in the Swiss Jura, a lofty chain which is composed of many parallel ridges with intervening longitudinal valleys, these features being caused by the fossiliferous strata taking the worn away until their former position has been taken by valleys (Fig. 173), the rainfall and the streams formed by the rain working into the numerous fissures and joints naturally to be found in such rocks. Anticlinal mountains, or those which coincide roughly with the greater folds of the strata—as the Alps often do—are, indeed, notoriously weakly built. Rockfalls and landslips are of frequent occurrence

* Ball: "Notes of a Naturalist in South America" (1887).

† The Austrian geologists also speak of *diaclinal*, *cataclinal*, and *anaclinal* valleys, according as they cut across the beds, run in the same direction as the beds, or run against the outcrop. They are shown diagrammatically in Fig. 175. But the subdivision is needlessly precise, though no doubt in mountainous countries which have been subjected to great disturbance, the nature of valleys is often extremely complicated—one section being of one character, and the remainder of different origins.

in them, while these mishaps are comparatively rare, and on a much smaller scale, among the immeasurably older mountains of Scandinavia and Scotland. The hills and mountains of Scotland have, indeed, long ago passed through that phase of unstable equilibrium which has cumbered the valleys of the

appear while a synclinal hollow remains after the ridges on either side of it have vanished, is demonstrated in the outlying fragments of rock which remain capping a hill after the strata of which they originally formed a part have disappeared. These beds will generally be found to dip into the hill—that is, they form

Fig. 176.—PEAK OF THE MATTERHORN, SWITZERLAND.

Pyrenees, the Alps, and the Apennines with chaotic masses of rock fallen from mountains which have not, as yet, got over the inherent weakness of anticlinal ridges. "After countless ages of erosion," Professor James Geikie remarks in referring to the stability of the Scottish hills, "our higher grounds have acquired a configuration essentially different from that of a true mountain chain. Enormous landslips, like that of the Rossberg (p. 280), are here impossible, for all such weakly constructed mountains have disappeared."

The tendency of an anticlinal ridge to dis-

part of an old pericline (p. 77). Had the rocks taken a different slope they could scarcely have remained, since their dip from the centre outward would have favoured landslips, and thus have tended to carry them all away. Hence, though the beds that remain form portion of a hill, they originally lay in a basin. This is the reason why anticlinal hills are rare in regions long subjected to denudation. Where they do exist, as in the case of the Ochils, it is because the rocks of which they are composed are of a more enduring character than those of adjacent strata. On the other

Fig. 177.—ORIGIN OF THE GANGES (BHÁGIRATHÍ) FROM THE GANGOTRI ICE CAVE (10,330 FEET) IN THE HIMÁLAYAS.

(*After a Photograph.*)

hand, synclinal hills are very common. Snowdon and Moel Hebog are, for instance, the stable remnants of synclinal folds in ancient strata, while the Bristol Channel, and most likely both ends of the English Channel, lie in valleys excavated out of anticlines. But it is more than doubtful whether any of the Western Scottish lakes have been due to folding of the strata which have formed valleys and closed them by tilting, so that the outlet for their drainage was stopped;* though it is possible that some of the Alpine lakes — especially those of the Italian Alps, like Maggiore and Como—might have been ancient fjords, projecting in the Lombardy Sea, and closed by the upheaval of the country. Many of the rivers, valleys, and lakes of the Scottish Highlands trend north-east and south-west, or in the direction taken by the anticlines and synclines into which the rocks have been folded. But several of the most marked hollows run along the anticlinal axes, or saddle-backs, while most of the conspicuous mountains are built up of synclinal or saucer-shaped strata. Loch Tay is a good example of the one, Ben Lawers of the other. "Thus," writes Professor Geikie, "in the geological history of the Scottish Highlands we may trace the successive phases through which many other tracts have passed. The Scandinavian plateau, and many of the mountains of Middle Germany —such, for example, as the Harz, the Erzgebirge, the Thüringerwald, etc.—show by their structure that they have undergone similar changes. First we have an epoch of mountain elevation, when the strata are squeezed and crushed laterally, fractured, and shattered—the result being the production of a series of more or less parallel anticlines and synclines, or, in other words, a true mountain range. Next we have a prolonged period of erosion, during which running water flows through synclinal troughs, works along the backs of broken and shattered anticlines, and makes its way by joints, gaping cracks, and dislocations to the low grounds. As time goes on, the varying character of the rocks and the mode of their arrangement begin to tell; the weaker structures are broken up; rockfalls and landslips ever and anon take place; anticlinal ridges are gradually demolished; while synclines tend to endure, and thus grow, as it were, into hills, by the gradual removal of the more weakly constructed rock masses that surround them. Valleys continue to be deepened and widened, while the intervening mountains, eaten into by rivers and their countless feeders, and shattered and pulverised by springs and frosts, are gradually narrowed, interrupted, and reduced, until eventually, what was formerly a great mountain chain becomes converted into a low-lying, undulating plain. Should the region now experience a movement of depression and sink under the sea, new sedimentary deposits will gather over its surface to a depth, it may be, of many hundreds, or even thousands, of feet. Should this sunken area be once more elevated *en masse*—pushed up bodily until it attains a height of several thousand feet—it will then form a plateau, composed of a series of horizontal strata resting upon the contracted and convoluted rocks of the ancient denuded mountain chain. The surface of the plateau will now be traversed by streams and rivers, and in course of time it must have become deeply cleft and furrowed, the ground between the various valleys rising into mountain masses. Should the land remain stationary, its former fate shall again overtake it; it will inevitably be degraded and worn down by the sub-aërial agents of erosion, until once more it assumes the character of a low-lying, undulating plain."

I have preferred to quote Dr. Geikie's own words, since it would be impossible to express more clearly or more concisely the leading facts involved in the origin and decay of hills which cannot be studied without at the same time taking into account the genesis of valleys; for "valleys have been exalted and mountains made low" by much the same cause, namely, "wind and weather," and more particularly by that form of it which consists in the erosive

* The "Constructive" or "Tectonic" Lakes of some writers, in contradistinction to the "Obstructive" ones, which are due to moraine or other *débris* barrier thrown across the mouths of valleys, and which, therefore, are not due to any structural or tectonic features (*tektōn* Gr. builder) in their basins (Davis, *Science*, September 16, 1887).

action of rivers. "Quodque fuit campus, vallem decursus aquarum fecit," are the words of Ovid in indicating the opinion of the ancients, and especially of Pythagoras, regarding the manner in which valleys have been formed. Thus in considering the rush of water as the principal agent in scooping out these portions of the earth's surface, the ancients, it would appear, were in this, as in some other respects, "older and wiser than we" were until very lately. *

Age of Valleys.—In every age of the world's history there must have been valleys; for at no period since the land appeared above the water has its contour been uniform, or its rainfall been free from the necessity of finding a channel for the discharge of its surplus, or the river deprived of the power of eroding, and therefore of deepening and widening its bed. But it does not necessarily follow that all of the present valleys are of great age. In the changes which the surface has undergone old valleys have been filled up and new ones excavated. It is quite common to find old river channels buried under loads of strata. These are frequently met with by the Californian gold digger in "drifting" after gold, and not uncommonly are rich in the precious metal;† and in the coal mines of Scotland the miner often sinks into channels entirely filled with sand, clay, and gravel, which indicates that they have been old river beds occupied to a comparatively recent period, and subsequently hidden under loads of accumulations dating from the Glacial Period. In the North of England we find old valleys in the mountain limestone filled up by the Trias, but again being gradually excavated by modern streams. At Gosau, in the Salzkammergut, and near Salzburg, there are old valleys in the Triassic beds, in which Cretaceous strata have been deposited, though these in their turn are being cleared out by the streams, which are eroding ravines through them.

* Jas. Geikie: *Scottish Geographical Magazine*, 1886, p. 160; Le Conte: *American Journal of Science*, 1878, p. 75; Callaway: *Geological Magazine*, 1879. p. 1, etc.

† The "tailings" or washings of the gold diggers are now prominent features in the scenery of the Pacific Slope. In California this clay covers great flats, and many of the rivers run turbid, or have become sensibly shallower by the mass of *débris* tossed in to them by the miners engaged in sifting their gravels or the gravels of their tributaries.

Fjords.

Intersecting the sea coasts of various parts of the world, more particularly in northern latitudes, are deep, narrow, more or less parallel, inlets, surrounded generally by precipitous cliffs, and varying in length from two or three miles to one hundred or more, which are widely known as "fjords," "inlets," "firths" (though the true firth is the continuation of an estuary), "canals," (in British Columbia) and (on the western shores of Scotland) "lochs." The nature of these inlets is everywhere identical, even though existing in widely differing parts of the world, so that they at once suggest a common origin. In the first place true fjords are either confined to the western shores of continents, or are found there more frequently and in a more pronounced form than on the eastern sides. Those of Norway, Greenland, Ireland, Scotland, and America, are apt instances.

Again, they are found only within certain latitudes. In Europe, for example, they do not extend south of Scandinavia, or in North America south of Vancouver Island. From the latter point the whole coast of the continent to Chiloe is an immense stretch of nearly straight line. But when the point mentioned is reached, the fjord-indented shore begins again, and appears in New Zealand also, the west coast of the South Island being, in many respects, an exact counterpart of the shores of British Columbia. In other words, we find the transition from a straight to an indented coastline coincides pretty equally with that from a dry to a moist climate, and the change from the dry climate of Chili to the moist one of Western Patagonia is accompanied, as we might expect, by a depression of the snow-line on the Andes. To put these facts in another way, fjords are only found either where glaciers have existed at some former period of the world's history (*see* Coloured Plate, showing the ancient and modern

distribution of glaciers), or where these rivers of land ice still grind their way to the sea. West coasts in high latitudes are particularly exposed to west winds — Maury's "counter trades"— which deposit on the high lands the moisture they have taken up from the sea.* It is therefore to be expected that in such regions glacier action would be most marked. We are therefore justified in concluding that these fjords were the valleys down which glaciers crept when the coast-line was higher than it is at present. The glaciers might not have actually gouged them out. They were originally valleys formed by streams draining down to the sea, or primeval hollows in the contour of the country. But the glaciers which afterwards took possession of these valleys scooped them out deeper. Indeed, at the present day glaciers are found at the head of many of them, in Greenland, for example, where they form the outlet for the icebergs, by which the glaciers which reach the coast relieve themselves. The western shores of this region are most markedly indented by fjords; but the eastern side has some of a sufficiently remarkable character, that of Franz Josef, which extends far into the interior and has tributary valleys, being one of the most interesting (*see* Coloured Plate, Vol. II.).

* Murphy: *Quarterly Journal of the Geological Society*, Vol. XXV., p. 354.

In Norway, however, as well as in British Columbia, and Alaska, and in New Zealand, there are not wanting instances of glaciers creeping down through the valleys at the head of the fjords, and, though they do not occupy the fjords of the West of Scotland, the glaciated sides and bottoms of these inlets are ample proofs of the purpose which they played when Scotland was, like Greenland of the present day, occupied by a vast "inland ice," and discharged icebergs from the seaward ends of its glaciers. Indeed, were the bottom of the Scottish "lochs" raised a little, they would form natural continuations of the land valleys at their head, and Sir Andrew Ramsay is inclined to attribute the fact of the Scottish lochs being in places deeper than the neighbouring sea to the grinding power of the ice that of old flowed down the valleys,† just as in like manner lake-basins have been gouged out by the same agent.‡

† For the literature of this subject the reader may refer to "Arctic Papers of the Royal Geographical Society," pp. 58–70; and for the latest views to "Meddelelser om Grönland," Vol. I., p. 184.

‡ Karl Pettersen considers, from observations made at Balsfjord in Norway, that this inlet "is not of glacial origin, but formed an incision or depression in the mountain of older origin than the Glacial age." I do not see sufficient grounds for accepting this generalisation, the leading facts all tending in the opposite direction. See also Helland, in *Quarterly Journal of the Geological Society*, 1877, p. 142, etc., etc.

CHAPTER XX.

Marine Denudation: the Formation of Coast Scenery.

The General Character of the Action of the Sea on the Coast—Only potent within Tide-marks—How the Waves Act—Instances of their Force—Destruction of Shores—Instances from the Frisian Islands, Holland, and Denmark—From the British Shores—Coast Platforms—Receding Lines of Cliffs and Raised Sea Beaches—Protecting Power of the Waves—Illustrations of this—Reconstructive Power of the Sea—The Shoaling up of Harbours—The Case of Romney Marsh—Sand Dunes—Their Formation and Action—The Wind—Plains of Marine Denudation—Sea Banks—The Dogger and the Newfoundland Banks—Sea Deposits, etc.

The influence of the sea in wearing away the land with which it comes in contact is perhaps more familiar to the unscientific observer than the like influence of rain and rivers; yet it is doubtful if the effects which it produces are quite so important, though, for the moment, often much more striking. At the same time the coast scenery, so far as indentations not produced, as in the case of fjords, by agencies proceeding from the land are concerned, is mainly due to the ceaseless dash of the waves, or to the unwonted rush of water during the wild storms, against which the cliffs serve as barriers. The deep bays at one place, the jagged rocks at another, the tall "stacks" or "needles" which form so prominent a feature in the scenery of some of the more Northern regions, the "drongs" of Shetland, the caves and arches, nowhere more noticeable than in the little island of Heligoland (*see* Coloured Plate of the North Cape of Heligoland), against which the sea has been so long unrelentlessly warring, are all due to the action of the sea.

How the Waves Act.—This action varies according to circumstances. In deep, quiet bays, where the tide is comparatively moderate, and the wind can have little action on the water, the wear of the waves is reduced to a minimum. But where the full roll of the Atlantic, the Pacific, or the North Sea breaks on the shore, the destruction is much greater. Again, if the rocks are hard, like so many of the Igneous and Metamorphic ones, they will more easily bear the brunt than when they are soft, easily eroded, or permeated by joints, fissures, or faults, which permit of the water entering, and gradually removing great blocks, into the place left by which the tide or waves enter, and hollow caves (Fig. 178).

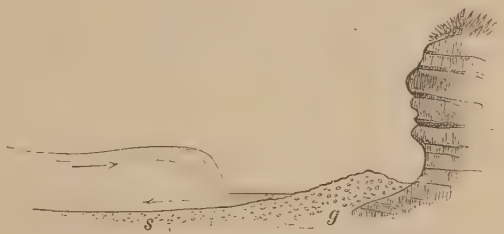


Fig. 178.—ACTION OF THE BREAKERS ON THE COAST-LINE.

g, Gravel; *s*, Sand. The arrows mark the course of the advancing and retreating wave.

The tides also help in the work of erosion, as twice a day they act as currents which sweep into the sea the materials which have fallen within their reach, or been torn from the cliffs by the action of storms—their height also depending to a large degree on the conformation of the coast. The sea, however, does not erode to any great extent beyond low water mark, where reefs and skerries so often mark the limit of its action. At the depth of fifty fathoms the influence of a commotion overhead is said to have been felt. But this is quite exceptional. The destructive power of the sea is only along the line of shore waves, or where the water can strike any obstacle Even then, except for the constant wear and tear which water always exerts, and the effect

the waves produce by driving water into every crevice of the cliffs against which they break, and by the compression of the air originally in the cracks or cavities, assisting in the dislodging of stones, the sea acts mainly during storms. Then it is that its power is demonstrated. At the Eddystone the engineer had to calculate that the force of the breakers during a storm was equal to 3,013 lbs. on the square foot. In the Pentland Firth the waves have been known to dash to a height of 70 feet and dislodge blocks between seven and ten tons in weight, and to heap rocks quite as heavy to the height of over sixty feet. Sir Henry De la Beche tells us that during gales masses of limestone and granite from two to five tons in weight were washed about at Plymouth Breakwater as if they had been pebbles. About 300 tons of such blocks were borne a distance of 300 feet, and up the inclined plane of the breakwater. In one place a piece of limestone, seven tons in weight, was washed a distance of 150 feet — though it must be remembered that a rock in water is much lighter than on land. Again and again, during the winter storms, the vast blocks of concrete which formed the foundation of the Wick Bay Breakwater were torn from the places where they had been lowered during summer and tossed about as if they had been corks. One of these, weighing about a thousand tons, was laid at the seaward end of the structure, and so secured that it was believed it would be able to resist any force which could be brought against it. But no sooner did the first winter storm try conclusions with the breakwater than the ponderous block was hurled from its place, followed in shoals by the smaller but still weighty pieces to which it formed the first line of defence. The strong iron bars, measuring about 8 inches by 3, by which the masonry was secured, were twisted into all shapes and broken, while masses of concrete weighing hundreds of tons were tossed about as if they had been small boulders. The result was, that after a vast sum had been expended in the vain endeavour to build a barrier against the sea, the effort was abandoned, and Wick Bay now holds in its capacious maw the monuments of man's futile efforts to war against it.

The Frisian Isles, and Holland. — During various storms the Frisian islets lying nearest the Holstein coast were formed out of the Nordstrand Peninsula, the waves breaking through the dykes which had been constructed to keep them out, and in a few hours disrupting it into a number of low sandy isles. The Sand Island which lies off Heligoland is gradually wearing away. It was separated from the Rock one (Fig. 9, p. 28) last century, and traditions still remain of a time when the island stretched over to the adjoining mainland. As for Sylt and the other isles to the northward, they are, and have always been, on the decrease, by means of the action of the waves;* and during the storms of 1872 many of the Danish islands were overwhelmed by the Baltic. The constant war which the sea wages against the Dutch coast is so familiar as to scarcely require more than a passing remark. Of late years, by raising barriers in its way, Man has been the victor, and is not only content with a passive resistance to the ocean, but is actually regaining some of his old acquisitions. However, the Zuider-Zee remains as a memory of the time (600 years ago) when the sea burst into Lake Flevo. Even now it is gradually silting up: most of its once famous harbours are half useless. Amsterdam is reached by an artificial canal, and a scheme is in contemplation which aims at draining the gulf and converting it into dry land. The district known as the Biesbosch—literally the "reed forest"—more than forty miles square, is another of the many "verdronken lands" of Holland. In 1421, by an eruption of the sea, 72 towns and villages were destroyed and 100,000 persons perished. A solitary tower is at present the sole relic of human habitations in this once smiling region, now choked with willows, reeds, and rushes.

* In "Peoples of the World," Vol. VI., pp. 246–55, I have given a fuller account of these remarkable devastations of the sea.

The east coast of the island of Zuid-Beveland is another "drowned land." In 1532 this fine agricultural region was inundated, and 3,000 persons perished. These cases, however, are more important socially than geologically.

The British Coast. — Along the British shores, though the contest between land and water is not waged with such frightful results so far as life and property are concerned, the influence of the waves, as might naturally be expected, is very strikingly exhibited, though the destruction is not going on throughout their entire extent. The hard rocks stand out defiantly in the shape of capes, headlands, and coast-lying islets, while the softer beds are indented by bays and inlets. Dingle, Kenmare, Bantry, and Dunmanus Bays are, for instance, eroded out of Shales and Limestones; while, according to Mr. Browne's description, the promontories separating them are composed of beds of indurated Sandstone. On the shores of Devon and Cornwall the creeks and coves are all scooped out of the shaly slate locally known as "Killas," while the Granite and Dolerite remain as headlands and capes. Polventon Cove, at one time notorious as a smuggling station, is, for instance, formed in this way; while the Merope Rocks, which afford it a shelter from the north-west winds, form a natural pier of hard Greenstone,* and on many parts of the Dorsetshire coast cove alternates with cape, or with bold range of cliffs in exact accordance with the softer or harder character of the rocks (*see* Coloured Geological Map of the British Islands). The Isle of Wight owes its lozenge-shaped form to its geological structure, the waves acting irregularly on its chalk, sands, and clays; and so violently have some parts of the eastern and southern shores of England been assailed, that it is now difficult to trace the sites of what were within historical times towns and villages along the Yorkshire, Norfolk, Suffolk, Essex, and Kentish shores, the rocks bordering the sea being in these counties mainly soft Sands and Limestones. For example, Auburn, Hartburn, Hyde, and Ravenspur (where Bolingbroke landed in 1399) are now non-existent. Their sites form sand banks dry only at low water. Since the Norman Conquest the coast has been calculated to have lost one mile in breadth, and more than two miles since the occupation of York by the Romans.

The site of the old town of Cromer is now in the German Ocean, and in 1829 a depth of 28 feet of water covered the spot where in Sheringham Harbour forty-eight years before stood a cliff 50 feet high with houses upon it. As for Shipden, Wimpwell, Eccles, and other churches, villages, and manors, their existence is now only known from historical records. Dunwich, in Suffolk, now a petty village, was once the chief port of the county, hundreds of houses, including the town-hall and the gaol, having been swept away, with monasteries, woods, roads, and graveyards. Kent furnishes many remarkable examples of the same erosive action of the sea. Sheppey Isle is rapidly diminishing, Reculver Church, which, in Henry VIII.'s time, was nearly a mile from the sea, being now upon a low cliff of clay and sand. Tradition insists that the Goodwin Sands cover Earl Goodwin's lands, and the poets are never weary of dwelling on the legend that off the Cornish coast there existed in the days of Good King Arthur a fertile region known as Lyonnesse:—

> "A land of old upheaven from the abyss;
> By fire, to sink into the abyss again;
> Where fragments of forgotten peoples dwelt."

Antiquaries wrangle over the exact spot where Cæsar landed: most likely the sea has long ago claimed the ground on which he first set foot. All along the Sussex coast we hear the same tale. Selsey Bill, which in A.D. 731 contained 5,220 acres of land, is now reduced to 2,880; and the place occupied by the cathedral and bishop's palace, in the time of Henry VIII., is now about a mile out at sea. From the west coast much the same tale comes, though there, owing to the harder character of the rocks and their greater height the

* De la Beche: "Geological Observer," pp. 59–60. In this work, as well as in Jukes' "Physical Geology" (1853), and Geikie's "Scenery of Scotland" (1887), may be found several excellent views of the effect of the waves on the English coasts.

destruction is not so great as in the lower and softer east and south coasts. Since the Roman period a considerable change must have taken place in the physical features of the estuary of the Mersey. But this is evidently due not so much to marine denudation as to the depression of the land. The submarine forests extending below high-water mark on both sides of the estuary with stumps of trees *in situ*, many bearing marks of the axe, the recorded inroads of the sea upon the land which formerly stretched much farther to the westward, the fact that a large portion of the Wirral Peninsula has now to be protected from submergence by a costly embankment, and other circumstances, all unite to prove that the level of the land has undergone material change. From these facts it has been inferred that previous to this change the channel of the Mersey formed a fresh water lake, extending from Runcorn Gap to Seacombe, fed by the waters of the Irwell and the Weaver, and the overflow discharged itself through Wallasey Pool and across a wide extent of marshy land into the sea, not far from the present embouchure of the Dee. The Needles of the Isle of Wight (Fig. 179), the Stacks of Duncansby Head, and other portions of the northern Scottish coast, particularly Caithness-shire, and the Drongs of Shetland, have already (p. 345) been referred to as monuments of the erosive power of waves.*

Fig. 179.—THE NEEDLES, ISLE OF WIGHT.

* The erosive power of lake waves is, of course, very much less than that of the sea, which have the tide to

Coast Platforms.—Waves act in two ways. The upper part of the breaker exerts all its force against the cliff or other portion of the shore, but, as seen in Fig. 178, the lower portion removes the broken material and sweeps it backward with the ebbing tide. It is thus, to a certain extent, conservative. In time a coast platform or roughly-formed step will be formed, as in Fig. 180.

Gradually the cliff at *b* will be reached by the waves, but meantime the *débris* fallen from it limits the action of the sea, and until the

Fig. 180.—COAST PLATFORM.

a, The point to which the cliffs formerly reached, but now covered at high water; *b*, The limits of erosion.

platform at *a* is broken down, and its wreck carried into the depths below the line where the erosive action of the waves can operate, or is swept by the currents along the coast, it is tolerably safe. In this way a line of cliffs—and there are sometimes several rows—is always the sign of an old coast. Sometimes these cliffs may be seen standing in the form of "scars" considerably inland, though, as we have already seen, an escarpment is not necessarily an old sea cliff. In these cases the coast is most probably rising or has risen, or some influence has been at work to prevent the sea from reaching to the base of the cliffs against which it beat at one time. Such old coast lines we have already adduced as a proof of the secular rise (Fig. 87).

Protective Power of Waste.—Such raised beaches also indicate another fact regarding marine denudation. When the sea beat against the cliffs, a considerable waste fell from above in the shape of loosened rock and earth, material washed down by the rain, or by freshets pouring over the precipice, in addition to the material the waves may have left at their base. In Norway the *débris* at the base of the cliff is so extensive that it is used for building purposes. This material, therefore, forms a sort of barrier against the encroachments of the sea (Fig. 181).

In Devon and Cornwall these accumulations from the cliffs and slopes are known as "Head," and the limestone breccias of the Rock of Gibraltar, imbedded in a matrix of calcareous grit and earth as hard as the limestone itself, are attributed by Ramsay to the broken bits of rock falling over the cliffs, or carried by heavy rains to the foot of the declivity where land shells are abundant. There the shells and stones become cemented together by stalagmite into a compact mass, the talus thus formed, to the depth of fifty feet, being so firm that it is quarried for millstones.*

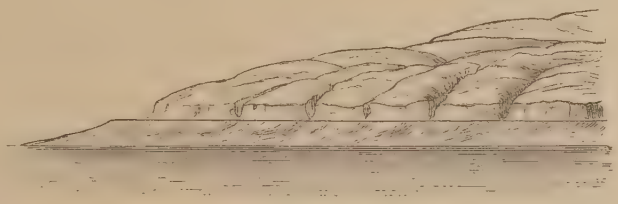


Fig. 181.—RAISED SEA BEACH BETWEEN VAAG AND SKAARLIODDEN ON THE NORWEGIAN COAST (69° 30′ N.). (*After Dr. Lehmann.*)

Reconstructive Power of the Sea.—Again, it often happens that the currents, by distributing the *débris* broken off the cliffs by the breakers along the coast in the form of sand and gravel, actually protect their base from the brunt of the waves. We know also that many parts of the coast, instead of being worn away by the sea, have actually been added to by it; notably the district known as Romney Marsh is a comparatively modern accretion,

aid them. But in some of the great lakes this action is by no means despicable. On this subject the reader might profitably study Mr. Gilbert's memoir on the "Topographic Features of Lake Shores" (*United States Geological Survey*, 5th Report, p. 80), when the lagoons formed by sandbars forming in front of bays (p. 515) are well illustrated in the case of Braddock's Bay and Long, Bucks, and Round Ponds in Lake Ontario.

* Ramsay and J. Geikie: *Quarterly Journal of the Geological Society*, 1878, pp. 505–41.

the River Rother, which gave Romney a capacious harbour, having altered its course in the reign of Edward I., and converted this old Cinque-port into what is practically an inland town. The estuary of the Thames which once separated the Isle of Thanet from the mainland, has been recovered from the sea partly by human agencies, but in a great measure by the silting up of the river, caused by the sea currents diverting its mouth in a northerly direction, by the travelling of sea beaches, and by the accumulation of blown sand.* The estuaries of the Dee and the Lune have been much silted up by the construction of weirs, which prevent the rush of back-water, and, Dr. Ricketts thinks, by the reclaiming of land on these shore margins contracting the tidal area, and thus diminishing the scour.

Sand Dunes. — Sand dunes have also an important influence in protecting the coast-line from the sea which formed them. These hillocks of blown sand are the sandstone rocks of the coast disintegrated into their original elements by the waves. For instance, the dreary sand hills which for miles border the city of Mogador, and are found, more or less, on different parts of the coast of Morocco, are the pounded-down gritty sandstone which appears along that portion of the African shore. These sand dunes are markedly seen on the Dutch coast and along the "landes" of the shores of the Bay of Biscay, where, until their farther progress was checked by the planting of pine forests, they were advancing at the rate of sixty or seventy feet per annum. On the northern coast of Cornwall the sands, "ever shifting" now, as when Arthur fought with Modred by "the phantom circle of a moaning sea," have invaded large tracts of cultivated land. They now form considerable hills, which are gradually being consolidated by the infiltration of carbonate of lime and oxide of iron, the one derived from the iron sand among the dunes, and the other from the comminuted shells which—as at Bude—form so large a portion of the beach that it is valuable as manure. In Western Australia the sand hills are often 200 feet or 300 feet high; on the German and Dutch coasts they are, if not so lofty, a good deal broader; and even on the north-eastern shores of Scotland the dunes have attained considerable proportions (p. 10). They, however, act as barriers to the encroachment of the sea, especially when they get bound together by carices, bent grass, and other plants; and cases are not lacking in which, by forming a great bar across the mouth of a river, the silt brought down by the stream accumulates until it becomes dry land.

This has occurred in the Yare, which must have formerly entered the sea close to Yarmouth, but, by the accumulation of sand dunes on its northern banks, its course has been altered until its present mouth is situated four miles farther south. Again, we may fittingly call attention to the fact that the ancient mouth of the Alde was originally at Aldborough; but it now passes for a distance of ten miles within a bank of shingle before it empties itself into the German Ocean (p. 315). In connection with this subject it is also worth noticing that most of the firths along the north-eastern seaboard of Scotland—Loch Fleet, Dornoch, Cromarty, Beauly, Inverness, and Moray—are conspicuous for the sand bars at their mouth, which have been thrown up by the tide above high water-mark, and run out from either bank.†

And here it is well to remark that all bays are not necessarily the creations of the waves. The Bay of Bengal cannot scarcely have been due to erosion. More probably, like the Gulf of Mexico, it is the remnant of some greater mass of submerged land.

We, however, already know that all drifting sand is not of marine origin (p. 8), much of that in Africa and Asia being due to the disintegration by the ordinary sub-aërial agencies of sandstone and sandy limestones.

* The chief facts regarding the wasting of the English coast may be found in Sir Charles Lyell's "Principles" and Mr. Jukes-Browne's work already cited so frequently. The British Association, however, appointed a Committee in 1882 to inquire into the subject. One report has been edited by Mr. Topley, and another dealing with the East Coast of England is ready for issue.

† Arch. Geikie: "Scenery of Scotland," p. 130.

In South West Africa Dr. Stapft doubts whether the dunes between the Namieb and the sea coast have been formed by the sand blown inland by the south-west wind. Rather, he is inclined to regard them as upheaved sea banks, which have been moulded to their present form by the action of the wind. The land in this region has risen in recent times (p. 71).*

Banks.—Sea "banks," like the Dogger and the banks of Newfoundland, are usually the result of a meeting of currents. In the latter instance they are caused by the *débris* dropped by icebergs borne down from Davis Strait by the current meeting here the Gulf Stream on its way across the Atlantic.

The wind, it may be added, is, when aided by sand, often an "Æolian agent" in rough-hewing the world which, though small, is not to be despised. For, as we often see even in this country, and still more notably in those where little rain falls, it acts, when driven before the winds, much as a "sand-blast" does. The rocks—as the writer has frequently noticed in California, and quite as remarkably on many parts of the British coast, at Burntisland, in Fife, for example—are polished by the friction of the flinty particles. In the Egyptian Delta, many of the ancient monuments, the Sphinx, for instance, are not only buried by the drifting sand (which protects them), but eroded by the same agency. Sometimes erect rocks will be "undercut" by the sand-laden breezes until they look like huge fungi, as do many of the upright blocks in Western America,† a land of extreme sub-aërial erosion.

Plains of Marine Denudation.—But though the sea is practically powerless to erode its bottom, except at a very moderate depth, every part of it which becomes dry land must in its turn suffer from the denudation just described. For as the bottom is elevated (p. 168), it will form a coast line, and then the waves and the tide will plane it into a more or less level slope.

This has been termed a "Plain of Marine Denudation." We see these slopes in most parts of the world, though naturally more marked in dry than in wet countries. For no sooner are they elevated than sub-aërial denudation begins to act upon them, and cuts the plain into gorges and watercourses. But still the original contour can be detected. For example, they are well marked, and on both sides of the Strait of Gibraltar—in Andalusia and Morocco. I have noticed these marine plateaux in travelling from Tangier, across the mountains to Fez, and Mr. Maw has described what appear to be uplands of the same character in various parts of Algeria, the coast of which has risen at least 600 feet in times geologically recent, for at that height shells of living species are found.‡

If the beds are in an anticlinal ridge, their slope and their top would be sliced off and shaved across by the waves, while if the strata lie in a syncline the tendency will be to form a plane sloping slightly, as follows from the retreat of the tide, but bounded by a more or less precipitous escarpment on the seaward side.

On the other hand, if the land sinks, the action of the sea will have a still greater play; for then more land will be brought within its reach, and when the elevation takes place a greater plain of marine denudation will be exposed; this alternating elevation and depression aiding in producing those series of platforms and range of inland cliffs, rising one above another, as in the Morea, each range pierced by caves and with an old shell beach at its base. The Isle of Wight is regarded by geologists as the remnant of a much larger land, the shores of which have been eaten into by the sea, and the Yare and Sandham branch of the Brading river as the shattered remnants of much larger streams, which flowed northward into the Solent before

* Petermann's *Geographische Mittheilungen*, July, 1887.

† Gilbert, in *Report of the United States Geological Survey West of the 100th Meridian*, Vol. III., p. 82. Mr. Green (*lib. cit.*, p. 109) also figures one of these mushroom-like stones, while the Brimham Rocks in Yorkshire furnish other examples. It is also possible, as has been suggested, that some of the "loggan stones" (p. 91) are due to wind erosion, though the rain plays the most important part in this form of earth sculpture.

‡ *Quarterly Journal of the Geological Society*, Vol. XXX., pp. 105—122.

their drainage basins had been destroyed by the sea. If the coast were raised sixty feet the Isle of Wight would be united with the neighbouring coast of Hampshire. Even the British Islands may be looked upon as a country which has been pared down by the action of marine erosion. For long distances round our shores the sea is not over 600 feet deep, while outside this comparatively shallow limit the

Fig. 182.—MICROSCOPIC SECTION OF THE CHALK OF MEUDON (MAGNIFIED 300 TIMES).

1. Textularia; 2. Globigerina; 3. Rotalia; 4. Coccoliths.

lead plunges at once into depths of 3,000 and 6,000 feet (500 to 1,000 fathoms), so that we are justified in regarding the intervening space as a plain of marine denudation, which, if elevated, would form a flat or steppe, more or less undulating, and with lakes only here and there in the deeper hollows, and sandy and gravelly esker-like ridges, where banks like that of the Dogger lay. On the whole, however, taking all the facts of the case into consideration, the sea does not erode the land to anything like the same extent which the subaërial agents do. Its power is limited, unless the coast is either rising or sinking, for, as the rise of the tide is limited, and the action of the sea is only powerful when the waves beat against the cliffs, a time must come when they will have to expend their force on a sloping sandy or shingly beach. If, however, the land sinks, then the sea gets a fresh surface to act upon, while it sweeps into the depth beyond the sandy slope formed by its previous efforts. In like manner, when the land rises, it can begin again with a fresh "purchase" on the old shore, though in this case it filches nothing from the land, but by removing the shingle, which acted as a protection to the cliffs beyond, it paves the way for an onslaught against them at a future period. In brief, while sub-aërial denudation works vertically cutting down, marine denudation acts horizontally cutting inwards (*see* coloured map showing Depths of the Atlantic).

Sea Deposits.—The combined influence of the forces described, acting now as in the past, are resulting in the formation of a certain amount of marine deposits. Along the European shores Edward Forbes recognised three zones, the *littoral*, which just marks the limit of the tide; the *laminarian*, which extends from seven to fifteen fathoms, marked by the presence of the great tangles which are seen floating beyond the limits of low water; and, still deeper, in the Mediterranean, a *coralline* zone, extending from 50 to 100 fathoms. These zones are, however, mainly distinguished by the shore vegetation.

Taking, however, the world at large we find littoral deposits, consisting of the *débris* which has been broken from the cliffs or washed down

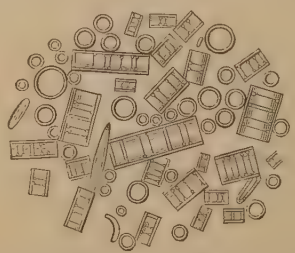


Fig. 183.—SECTION OF THE "TRIPOLI," OR POLISHING SLATE OF BILIN, IN BOHEMIA, COMPOSED OF SILICIOUS-CASED DIATOMS (MELOSIRA [GALLIONELLA] DISTANS).

by rain and rivers. Hence it is mixed, and exhibits false bedding in a more marked form than deep-water deposits. In it, also, burrow the shells of shore molluscs, such as cockles

PLANTS OF THE ALPINE REGION (THE NORTH LIMESTONE ALPS)

(IN THE BACKGROUND IS THE DACHSTEIN WITH THE GOSAU GLACIER).

(*Cardium*), razor-shells (*Solen*), periwinkles (*Litorina*), limpets (*Patella*), mussels (*Mytilus*), *Natica*, *Cerithium*, and many Foraminifera (*Alveolina*, *Amphistegina*, &c.), and a host of other bivalves and univalves found in shallow or comparatively shallow water off the coast, embedded in sand, clay, or mud, with marine plants and others, decidedly of terrestrial origin, which have fallen over the cliffs, been blown into the sea, or been washed down by the river. In like manner signs of terrestrial proximity are shown by land animals being found mingled with sea species, by conglomerates composed of consolidated gravel beaches, and, in certain cases, breccias, made up, as in Gibraltar, of *débris* which has tumbled over the cliffs, though it has not been subjected to the abrasive action of the waves.

In deeper water we find a *sub-pelagic* zone, which also contains, though in less quantity, mud and silt, which may be of terrestrial origin, though never more than 150 geographical miles from the coast, which is about the limit to which the influence of such a river as the Hoang-ho extends. These sub-pelagic deposits are all more regular in their formation, their littoral ones pointing to still waters and a bottom undisturbed by river currents, waters, and marine currents. The sub-pelagic deposits are characterised by the presence of Crinoids, or Stalked Starfish, of Sea Urchins, or Echini, of Cephalopods, or Shelled Cuttlefishes, like the ancient Ammonites and the modern Nautilus, of Brachiopoda, or carriage-spring shells, of Pteropoda, which float on the surface, and sometimes by the remains of univalves and bivalves (*Pleurotoma*, *Fusus*, *Murex*, *Conus*, *Scalaria*, *Dentalium*, *Leda*, *Nucula*, *Corbula*, *Solenomya*, *Tellina*, *Lucina*, &c.); along with deep-sea and insular corals (*Isis*, *Corallium*, *Flabellum*, *Turbinolia*, *Caryophyllia*, &c.), and sponges and many of the lowly-chambered shells known as Foraminifera (*Globigerina*, *Cristellaria*, *Orbulina*, &c.). (Fig. 12.)

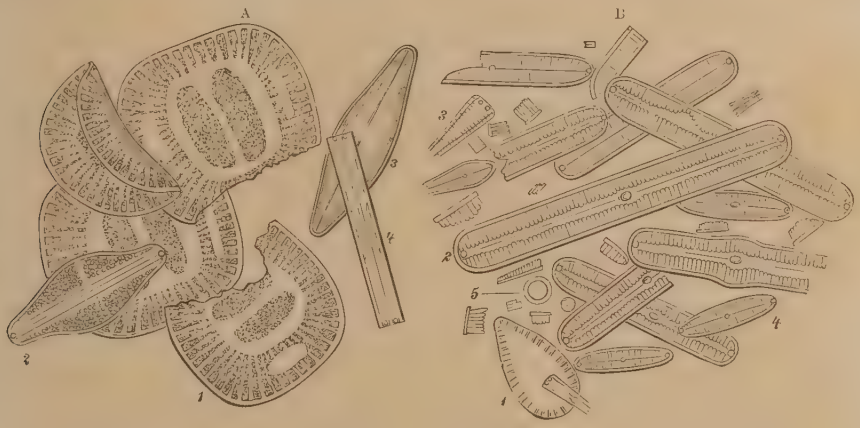


Fig. 184.—DIATOMS FROM THE "KIESELGUHR" OF FRANZENBAD AND THE "SOOS" AT EGER IN BOHEMIA.

A. 1, Campylodiscus clypeus; 2, Navicula sculpta; 3, Upper side of the same species; 4, Edge of Navicula bohemica.
B. 1, Surirella striatula; 2, Pinnularia viridis; 3, Gomphonema truncatum; 4, Navicula gibba; 5, Melosira (Gallionella) distans.

In the distinctly pelagic deposits (that is to say the Deep Sea formations) which formed or are forming far from the coast, in the abyssal depths of 500 fathoms or more, we find no trace of land *débris*, though many of volcanic eruptions, such as pumice-stone and various minerals mingled with the red clay already described (p. 35), and manganese nodules. Shark's teeth and the ear-bones of whales are numerous, though mostly, except in a few instances, of modern species of Cetacea. Here also are found many Foraminifera and Diatomaceæ

(Figs. 183, 184), as might be expected, since they not only form deposits in lakes, but both in the north and in the south give a peculiar colour to the sea and to the ice fields floating in it. In the Antarctic Ocean they form, according to Sir Joseph Hooker, a submarine deposit consisting entirely of their silicious shells; and I have shown that another species closely allied to that figured on p. 352 imparts the peculiar green colour characteristic of the Arctic Ocean. These facts, it will be seen, have an important bearing on the origin of deposits of geological age, albeit all deposits deserve that name; for the past is continuous with the present. This theme will, however, come to be discussed at a later date in our studies.

CHAPTER XXI.

Ice: Fresh-water and Marine: Ice Caverns: Glaciers: their Origin and Action.

Nature of Freezing—Disruption by Frost—Fresh-water Ice—Anchor Ice—Sea Ice—Characteristics—Thickness—Polynia—The Ice Foot—Geological Influence of Sea Ice—Ice Caverns—Description of some of the most Remarkable—Glaciers and the Snow Line—The Névé—Movement of Glaciers—Crevasses—Moraines—The Sub-Glacial River—Ice Tables and Ice Cones—The Moulins—Polar Glaciers—Inland Ice—Icebergs—Former Distribution of Glaciers—Ice Markings—Travelled Blocks, etc.

When its temperature falls to 32°, fresh water, under ordinary conditions, solidifies into the form of ice. In freezing it expands, so that, as we see familiarly in the case of water-pipes, it will burst any vessel which it filled when in the liquid condition. If under pressure, water takes a greater amount of cold to solidify, though the moment the pressure is removed, it will congeal, expanding, of course, in the process. This it does with prodigious power. If, for example, it does not freeze until the temperature falls two degrees below the ordinary freezing-point, the force exerted on the cavity in which it is confined has been calculated to amount to 138 tons on the square inch, and so on in proportion. Hence it need not be a cause for surprise that a bombshell filled with water and hermetically sealed bursts when subjected to cold sufficiently great.

Disruption by Frost. — Water, when it lodges in fissures, can usually expand in freezing without doing very much damage, freezing generally occurring at 32°. But when it is contained in cavities in rocks, the conditions necessary for this enormous pressure, namely, congelation below the ordinary freezing-point, are sometimes attained with the result that the rocks are torn asunder or disrupted in various ways. This is the reason why, after a thaw, some rocks appear almost as if pulverised, while others are forced out of the ground as if some internal movement had burst the soil. Hence in Alpine countries a concomitant of winter is usually the tumbling down of great masses of rock; while in the Arctic regions no sound is more familiar during the long, lonely, silent night than the loud reports caused by cliffs being torn asunder by the water expanding in the crevices, cavities, or other fissures in their mass. Indeed, the waste which rain causes farther south, is in the north paralleled by this continual action of the frost during some eight or nine months in the year, though the principal destruction takes place during the first few days of every winter.

Fresh-water Ice.—The rivers in high latitudes or in the interior of northern continents also freeze over during winter, and when the ice breaks up during spring, the great sheets roaring and rushing seaward abrade the banks, and carry far from their original site the earth, rocks, and other waste which has fallen on them from the crumbling cliffs

disrupted by the frost or eroded by the freshets of those sudden thaws, which are not uncommon in Northern America, Europe, and Asia. Sometimes in narrow channels the disrupted sheets of ice join and form a "raft" which for a time dams back the stream, and when the barrier gives way, bursts with tremendous force, carrying all before it. In this way, by the force of the rush of water bearing the pile of ice against the shore, earthen banks have been undermined and low islands in time worn away. In the St. Lawrence, for example, Crab Island, which at the beginning of this century was an acre and a half in extent, is now only marked by shallow water over the spot where it existed. In the Siberian rivers, which flow from south to north, the ice in their upper portion is thawed, while that in the lower reaches still remains firm from bank to bank.* Hence by the floating ice piling itself above the fixed, great dams are formed, causing much damage, and in some respects resembling the lakes accumulated by a glacier sliding athwart a stream, as has happened more than once, in the Himalayas, for example (p. 297), and in Switzerland, where, in 1818, a tunnel had to be cut through one which extended across the Dranse Valley in order to permit the accumulated waters of the stream to drain away.†

Anchor Ice.—When a stream is shallow, ice will adhere to the bottom; but even in deep rivers and lakes, when the bottom is rocky or stony, if the water is shallow compared with what it is higher up the stream, or the current is swifter and the water rougher compared with what it is immediately above, "anchor" or "ground ice" forms on the bottom and rises to the surface,‡ carrying with it in some cases gravel, sand, and other materials. This will happen when the surface of the water is quite unfrozen. As a rule, however, it is spongy, slushy kind of ice, arranged in vertical flakes. This anchor ice, or "frazil," as it is called, is by some observers—Sterry Hunt, Bell, and Arago—considered to be due to terrestrial radiation. But this does not explain all the phenomena, and the idea of Zschokke that the anchor ice is formed on the surface and carried to the bottom by the current, seems to agree better with the facts (Weber and Rae), since it is doubtful whether water is so penetrable for dark rays that the radiation can have any effect on the formation of the "frazil." In the Baltic harbours, where the water is only brackish, large stones, ropes, chains, and even anchors, are known to have been raised to the surface by the large masses of ground ice formed around them.

In ponds which freeze to the bottom boulders are incorporated in the ice. As the ice is evaporating at its surface, while accessions of water lift the ice, the boulders are raised, and gradually carried towards the periphery. On large lakes the drifting ice is pressed against the shores, and thus forms dykes of boulders.§

Sea Ice.

Much more important, however, than the ice formed in rivers and lakes, is that which covers the surface of the sea in very high northern latitudes during the coldest months in the year. The temperature at which salt water freezes varies from 26°·7‖ to as high as 31°, the degree depending entirely upon the saltness of the water. This (*See* Map showing the Distribution of Saltness in the Sea) we know varies considerably in different parts of the ocean, and in the Arctic region depends upon the amount of fresh water which may be pouring into any of the numerous land-locked

* Seebohm: "Siberia in Asia," p. 91.

† The Märjelen See is another lake of much the same character (Tyndall's "Forms of Water," I.—IV., pp. 136–138).

‡ Rae, in *Nature*, Vol. XXI., p. 538.

§ Bell, in *Science*, Vol. IX., No. 217, p. 324; Zschokke: *Verhandl. der naturf. Ges. in Bern*, 1855, p. 169; "Das Grundeis," p. 186; Weber: "Die Entstehung des Grundeises," etc. (1856); Scoppewer: "Ueber Grundeis," p. 20.

‖ Ashe (*Science*, Vol. IX., No. 228, p. 592, and Vol. X., No. 232, p. 36) found this to be the temperature at which the sea at North Bluff, Hudson Strait (lat. 62° 33′ 45″ N., long. 70° 41′ 15″ W.) froze, though, as the Northern waters are of less specific gravity than those more Equatorially situated, a different result might have been expected. His mode of arriving at this result is, however, open to criticism. See Boas, in *Science*, Vol. X., No. 239, p. 118, and Buchanan, in *Nature*, April 28th and May 5th, 1887.

bays, or the amount of snow which has fallen on the surface and melted. The average is 28°·8. The first thin ice formed is really fresh: it is often nothing more than the melted snow of the surface. The effect of the cold seems to be to precipitate the salt, since, except for the brine included among the crystals, the ice itself is frequently little more than brackish, this brackishness being mainly due, first, to the cause mentioned, and, secondly, to the top of Baffin's Bay, becomes covered with ice, over which the deep snowfall forms a white blanket, the surface of which glimmers with a weird brightness under the moon and stars, or when the aurora affords a more fitful light in the long Arctic night of four months which prevails there. But the ice is not smooth or even (*See* Coloured Plate of a Midsummer Night in the Arctic Ocean, north of Behring Strait). The tides and the currents,

Fig. 185.—ICEBERG, AND PART OF A POLAR ICE FIELD.

the infiltration of salt water from the sea below by means of capillary attraction.* The ice thus formed is of an azure blue colour, and of great density. Compared with the sea water of which it is composed, it is as 0·922 to 1000, and in floating one part is above the water line and fourteen and eight-tenths below it. By-and-by, as the winter advances, the sea, as at or the wind, have forced it into "torroses," to use the Russian word, or "hummocks," as the Scottish whalers call them, so that the "pack ice" is often as if the ruins of a town had been tumbled on the surface of an ice sheet, and then covered with a coating of snow (Fig. 200).

Polynia.—It is, however, rare to find the ice quite continuous during winter. "Polynia," or open spaces, are quite common, and out of them the ice smoke, or the evaporation in the shape of little spiculæ of ice, often rises during the winter, while herds of white whales and other cetaceans crowd the narrow area of these breathing-holes. In Hudson Bay and other places there are long fissures in the ice which remain open throughout the winter.

* In this place I have given only such particulars as are necessary for the understanding of what follows. In "The Countries of the World," Vol. I., pp. 48–71, will be found many details which it has not been thought expedient to go over again. So far as sea ice is concerned, the reader may be referred to Weyprecht's "Die Metamorphosen des Polareises" (1879), which, in spite of much to which exception might be taken, is the only full treatise on the subject.

Temperature, Dr. Bell thinks, has no influence upon their breadth. They form every winter in the same situations, and generally between the extremity of points on opposite sides of the water. He considers it probable that the progressive lowering of the water going on during the winter produces a tension on such places sufficient to keep the fissures open.

Thickness.—The thickness of an ice field depends, of course, mainly on the temperature, though, as the "Palæocrystic ice" proves, the amount of snow and other circumstances enter largely into the causes to which it is due. About eight feet is, however, the average thickness which a sheet of sea ice will attain in the course of winter if it is not disturbed, though in Smith's Sound, Hayes will have it that an ice table has been formed by "direct freezing" to the depth of 18 feet.* But though the thickness which ice attains in free formation is comparatively small, fields of ice are met with 30, 40, 100, and even 1,000 feet thick. But these are the result of the forcing of ice sheets over one another by pressure, and are known as old ice, which differs from young ice by its greater density. Or it is formed after the manner of the "Palæocrystic" ice. This term, though devised to express an altogether mistaken theory, which has since been abandoned by its author, may still be conveniently used to describe the vast thickness of old-packed ice which is found in the upper reaches of Smith's Sound. But these fields are not eternal or immovable, and the Palæocrystic Sea differs in no respect from many other portions of the Arctic ocean, except that it is of greater area and covered with a greater extent of old ice, which seldom breaks up, and is therefore not melted every summer, or, indeed, except when it drives south—which it has a difficulty in doing through the narrow gut of Smith's Sound—never melts in its entirety. In brief, the Palæocrystic ice is formed as any other ice field is. But the great thickness of the ice is due to the accumulated snows of years. The névé-like stratification, the embedded atmospheric dust, and the chemical character of these polar floes indicate that they are the accumulated snowfall of ages rendered brackish by infiltration and efflorescence. This was the opinion of the late Dr. Moss—an opinion to which General Greely gives the force of his acquiescence. If Polar floes, from a hundred to a thousand feet in thickness, are formed by direct freezing, as Nares imagined, the Polar lakes, which are subjected to greater cold than the sea, would be frozen to the bottom. This, however, is not the case. In Lake Hazen, for example, Greely noticed that the main ice was movable by the wind, as shown by the fact of the extensive ridges of small stones formed by its pressure on the shore.†

The terms "patch," "floe," "field," and so forth, are used to express the relative magnitudes of the ice, though the word "floe" is very generally applied to every kind of sea ice without reference to its size. Sailors talk of land ice when they mean not ice found on land, but ice which lies along the coast, or which adheres to a group of islands within a sound, and is therefore of great value in sledge expeditions.

Disruption.—But, unless in the very exceptional cases indicated, sea ice breaks up every summer. Indeed, the hummocks which relieve the continuity of its original flat surface, and give it the appearance of a rugged country, are the result of the unrest, which is the characteristic of a sea coursed over by currents and disturbed by winds, tides, or by the swell which reaches it from the ocean. The effect of this is seen in the broken ice on either side of a "lead," this rubble being caused by the crushing of the edges of two floes against one another. As spring and summer advance the great fields part, until black road-like "leads" of open water show themselves throughout their extent. In search of these leads the Arctic navigator eagerly courses along the free edge of the ice, and frequently, unless he can manage to cut a dock or space in which to

* "Hayes: "Open Polar Sea," p. 489; Payer: "New Lands Within the Arctic Circle," Vol. I., pp. 1–18; Nares: "Voyage to the Polar Sea," Vol. I., p. 314.

† "Three Years of Arctic Service," Vol. I., p. 280; Vol. II., p. 48.

incase his vessel before the floes move towards each other, is caught between the treacherous portions of the disrupting ice, and is crushed as if his vessel had been a toy boat. All summer the Arctic sea is cumbered with these floating fragments of the winter's ice, the pieces being of all sizes, while outside the larger sheets is an oozy, broken-up mass, generally known as "brash ice." These broken or breaking up fields are "rotten." The snow that had fallen during the winter is melting, and the heat of the summer rapidly evaporates the surface of the ice, while the dash of the liberated sea against their edges sounds with a peculiar crackling noise as the water penetrates the increasingly oozy mass. The colour of the ice is by this time of a delicate azure blue, with yellowish spots, due to the presence of innumerable diatoms, which also appear in brown slimy masses from the under surface of the floes when the iron-shod prow of the vessel crashes through their decayed mass.* After a very cold night or a sudden fall of temperature it is noticed that the ice fields break up much more rapidly. This is no doubt due to the expansion of the re-frozen thawed water in their interstices, or of the sea water, which in spring is permitted to work its way in through the opening pores between the crystals, as well as to the sudden contraction and splitting due to a very similar cause. At this season the northern navigators are able to detect the presence of great unbroken ice fields from a long distance, by the "ice blink"† or light reflected from the snow just under the stratum of air in which the phenomenon is seen. In like manner the "loom" of open places is shown by the "water sky" or the dark spots on the horizon produced by the formation of clouds from the ascending mist due to evaporation.

Ice Foot.—But often long after the ice fields have been broken up in all except narrow straits or among the intricate channels between islands a rim of ice a few feet broad still clings to the shore. This is known as the "ice foot." In high latitudes or in places where the tide has little influence, this ice foot may be considered as the remains of the land floe. But when the tide rises and falls with some force it admits of another explanation. As Dr. Boas puts it —and his experience was entirely of the most southern part of Davis Strait—it reaches from high-water to low-water mark, gradually decreasing in thickness, and having a vertical edge. The process of its formation "begins before the sea is frozen over, and as the water is still agitated by winds the thickness of the layer formed during a single tide is considerable. This process is going on during the winter, and then the ice foot continues to increase in width. At spring tide its level is overflown by water, which adds to its height. It is characteristic of this ice foot that the unbroken land floe extends to its foot, a single crack separating the two masses."

Geological Influence of Sea Ice.—During winter and spring, loads of earth and rock tumble from the cliffs overhead, and either lie on or become embedded in the ice foot. Then when the ice gets free, this mass is either deposited in the sea, or is carried on the ice raft to a distance, or is driven against the shore by the force of the tide, currents, and wind, grinding the softer rocks with which it comes in contact, or undermining the high shores against which it is driven. In the Baltic, ice fields are sometimes stranded high and dry on the shore, with their load of *débris*, and Keyserling tells us of a granite block being landed 30 feet above the ordinary sea level by the ice sheet in which it was lying being forced to that height by the wind and waves. In the shallow waters of the Baltic the rocks are often scratched and ground by these ice sheets with their embedded stones, in much the same way as the moving mass of glacier ice scratches and grinds rocks. Funk Island, near Newfoundland, is described by Mr. Milne as visibly worn down by the ice floes from Baffin's Bay and Labrador impinging against it, while its northern end is covered with erratic boulders derived from the same source. Boulders have

* This I have described in a paper on the discolouration of the Arctic Seas in the *Transactions of the Edinburgh Botanical Society*, Vol. IX., pp. 244–252.

† In South Greenland, the Danes apply the term to the front of the great glacier which protrudes in 62° 32′ N. lat. ("Countries of the World," Vol. I., p. 62).

indeed been borne from the Labrador coast on ice sheets from long distances, and in the Gulf of Finland great blocks are often torn from the shore and conveyed far from their original site. * The result of ice fields thus grinding along the coast is that it is very common in the Arctic regions to find a uniform depth amounting near the shore to from 13 to 33 feet, but afterwards increasing only gradually and remaining unchanged over extensive areas. Another remarkable effect of the action of ice is that all the blocks of stone found in the sea are forced up on land, these blocks and boulders forming, in places in the Kara Sea, a nearly continuous stone rampart going to the sea level, while in front of it there is a quite even sea bottom without a fragment of stone. † A somewhat similar phenomenon is seen in lakes (pp. 355, 357).

* Nares: "Voyage to the Polar Sea," Vol. I., p. 276; Feilden and Rance: *Quarterly Journal of the Geological Society*, Vol. XXXIV., p. 566; Milne: *Geological Magazine*, Dec. 2, Vol. III., p. 408: Hind: *Canadian Naturalist*, N.S., Vol. VIII., p. 236, etc., etc.

† Nordenskjöld: "Voyage of the *Vega*," Vol. I., p. 188.

Ice Caverns.

In certain circumstances we have seen that ice may be formed in the earth after a depth sufficient to render it independent of the surface temperature—and yet not subject to that of the central heat—has been reached (p. 83). ‡

Ice Caves.—Ice is also found in some caverns which, owing to their great height above the sea, their great depth beneath the earth's surface, their exposure to certain winds, the subsidence of cold winter air into them, or several of these circumstances in combination, are unaffected by ordinary climatic conditions (Figs. 186, 187).

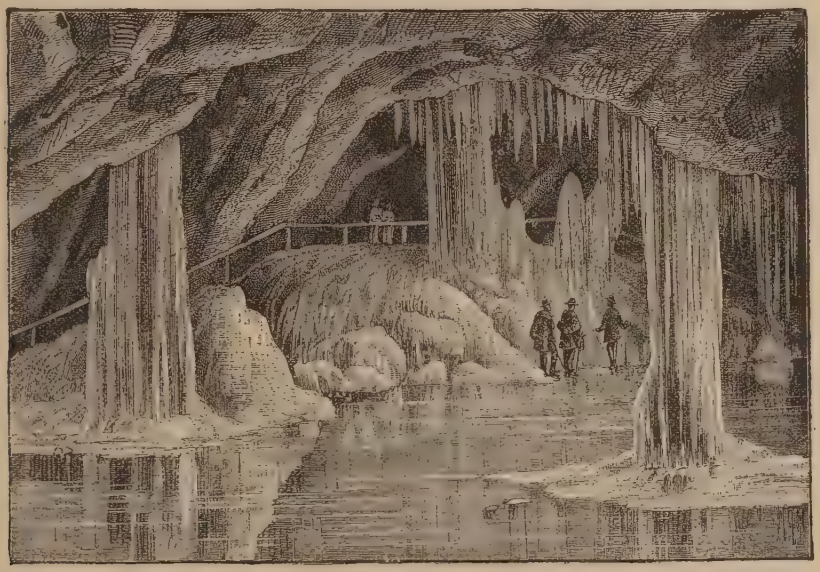


Fig. 186.—THE ICE SALOON IN THE ICE CAVE OF DOBSCHAU, IN HUNGARY.

In these ice caves, or "glacières," vast quantities of ice are formed which are not melted, even when the summer temperature of the cavern is above freezing-point. Hence there is an ever-increasing, or at least a never diminishing, permanency of ice. The water flowing from these caves is, of course, extremely cold, and it is more than possible that some

‡ *Report of the British Association* for 1887; *Proceedings of the Royal Geographical Society*, 1886, p. 740.

very cold springs, the low temperature of which cannot otherwise be explained, are due to the fact that they take their origin from a melting mass of the kind indicated. Such caves are known in various parts of the Continent — in France, Italy, Hungary, Switzerland, and Transylvania, fifty-six having been described from the Alps alone. The ice supply of the Island of Teneriffe has long been obtained from such a cavern, situated at an elevation of 10,000 feet on the Peak. The ice obtained is, as is usual with that from these caves, peculiar not only in its columnar appearance, but in the fact that it is less easy to melt than ordinary surface ice. The caves of the Untersberg, at Salzburg, of the Kolowrats, near Skerisora, in Transylvania, &c., are well known. But the cave discovered in 1870 near Dobschau, in Hungary (Figs. 186, 187), is even more remarkable. Here the ice is in a stalactitic form, while the difference between the summer and winter temperature is only a few degrees.*

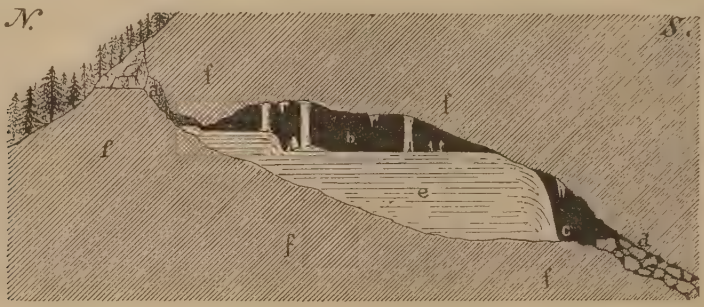


Fig. 187.—SECTION OF THE DOBSCHAU ICE CAVE. (*After Krenner.*)

a, Entrance into the limestone cavern; b, The upper cavern, which forms an ice saloon, with three ice pillars, an ice pavilion, and an ice hall; c, Lower corridor, with ice walls; d, Outlet of the water among blocks of stone; e, The great blocks of ice; f, The limestone rock. N, North. S, South.

Glaciers.

The snow which falls on lowlands or on moderate elevations in southern countries disappears during summer. But when a very elevated position is reached this is not the case. A part only vanishes. Hence, on the upper reaches of lofty mountains there is perpetual snow—that is to say, the winter's fall is not entirely melted by the summer's heat. Accordingly, unless it relieves itself, the load will go on increasing year by year. But the point above which there is perpetual snow varies in height according to the latitude in which the range is situated—being low down far north and high up far south. The limit below which the snow, taking one year with another, does not lie all the year round, is known as the *snow-line*.

Snow-Line.—Yet this line is not easy to define. Theoretically, it is that "isohypse" (line of height) below which, during the course of the year, just as much snow falls as the sun's warmth, during the same period, is able to melt. But it necessarily follows from that definition that the snow-line varies in time and space—in space moving its position up and down the mountain side, according to its position with respect to the points of the compass, the northern aspect being colder, the southern warmer; and in time varying from year to year, in accordance with the "meteorological vicissitudes" of the place. Hence it is necessary in trying to fix the snow-line to take into consideration not the masses of snow gathered into gorges or ravines impenetrable to the sun, but the facts deduced from

* The ice caves of Switzerland and France are described in Mr. G. F. Browne's special work on the subject, and that of Dobschau in Dr. Krenner's monograph, "Die Eishöhle von Dobschau" (1878). See also Lowe, in *Nature*, Vol. XX., p. 151; Thury: *Bibliothèque Universelle de Genève*, 1861, etc.

Fig. 188.—THE GLACIER SYSTEM OF MOUNT COOK, IN THE SOUTHERN ALPS OF NEW ZEALAND.

(*After a Sketch by the late Sir Julius v. Haast.*)

a long series of observations as to the precise altitude to which the *continuous* snow covering descended before the first fall of permanently abiding snow in autumn. Various other methods of fixing it have been proposed, but that mentioned is the one most commonly employed, and for all practical purposes is quite as good as any other. It must therefore follow that the determinations arrived at by different authors will differ in some respects, though the data recorded may be regarded as a very close approximation to the truth. The following table exhibits a few of these facts:—

Place.	Latitude.	Height of the Snow-line in feet.	
Spitzbergen	77° North lat. (Hornsound)	1,509	
Iceland	65° „ (Österjökul)	3,071	
Norway	70° „ Interior	3,349.	On the Coast, 2,900
„	60° „ Interior	5,512.	„ „ 4,462
The Alps	45–47° Western and Middle Alps	8,858.	Eastern Alps, 9,186
Caucasus	41–44° Eastern side	14,107.	Western side, 11,712
Himalayas	27–34° towards India	16,207.	Towards Tibet, 18,603
Karakorum	28–36°	18,394	
Africa: Kilimandjaro	3° South lat.	16,403	
The Andes—under the Equator	„ „	15,713	
„ „ Bolivia	16° Eastern Chain	15,911.	Western Chain, 18,438
„ „ Chili	33° „ „	14,763	
„ „ Patagonia	42° „ „	6,004	
Straits of Magellan	52·5°	3,609	

The snow-line thus varies from year to year, though on the average of a great many seasons it is tolerably uniform. Its height depends on latitude and exposure, being low in high latitudes and high the nearer the tropics are approached, the eternal snow attaining to the sea-level in the far north, while in the south it retreats from the warmth of the plains to a point where it meets, high in the upper reaches of the air, with the requisite degree of coldness. It also varies according to the exposure of a mountain range. It will even be at different levels on the two sides of the same peak. For instance, in the Hohentauern, in the Eastern Alps, the snow-line is at 9,000 feet on the north side and at 9,350 on the south side, and ascends still higher on those parts of the chain which project farther to the south, namely, 9,515 feet.*

Névé.—The snow which thus accumulates above the snow-line cannot, of course, remain for any length of time. Otherwise the mountain would soon—were this possible by the laws of Physics—assume the form of a gigantic mushroom. It melts to a slight extent during the heat of the summer day: evaporates to a still greater extent, and when it falls on a slope has a tendency to slide down in a snow-slip, or *avalanche*, as it is called in the French-speaking portion of Switzerland, or a *lawine*, as it is known among the Germans. The *staub-lawine*, or dust-avalanche, is composed of loose, fresh-fallen snow: the *grund-lawine*—which occurs in spring, and often causes immense damage, sweeping, as it does, everything before it—is a mass of more compact and, on that account, more destructive snow. But immediately above the snow-line the snow which remains is granular, owing to the water trickling into its mass and freezing round the crystals. This process of alternately freezing and thawing is repeated year after year until the snow becomes stratified, the different strata being divided by "dirt-lines" (Fig. 196), each line marking the crust of the

* Brückner in *Meteorologische Zeitschrift*, January, 1887.

previous year's snow by the dust, grit, leaves, insects, or other jetsam and flotsam which the wind may have deposited upon it. This granular mass is the *névé*, or *firn*. It is not ice, but it is the beginning of the ice river or glacier. On the flat summit of a mountain it would not be likely to accumulate, the wind sweeping it away, while on a slope the avalanche might relieve the mountain of the burden. But in the "corries" or "cirques"—those

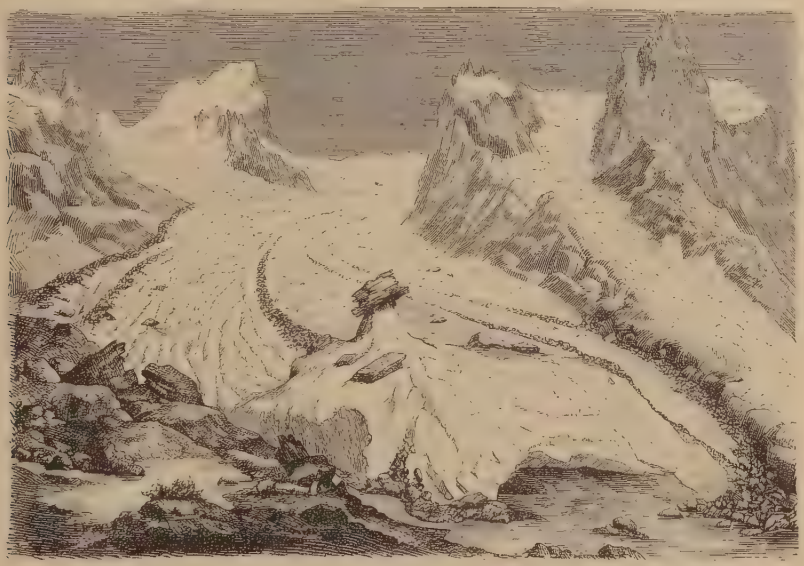


Fig. 189.—IDEAL GLACIER. (*After Simony.*)

deep, basin-shaped hollows at the head of so many upland valleys*—the snow accumulates, until it is pressed into blue, compact, crystalline ice, owing to the air bubbles, which give to the névé a white appearance, being squeezed out. The névé formed in these hollows is the fountain-head of the glacier, the reservoir from which it draws the supply of ice which moves into the valley below (Fig. 189). Between the névé and the snow remaining behind is a chasm (the "bergschrund").

Glaciers †.—These white ice rivers form one of the most remarkable features of Alpine and Arctic countries, moving as they do imperceptibly through the valley with a motion the exact counterpart of rivers. That is, the top and middle move faster than the sides and bottom, which are retarded by the friction of the ground over which they move, or with which they come in contact, being broad or narrow according to the area of the valley which they fill. They unite with one another like tributary streams, and then

* Most probably if not originally formed by converging streamlets, they have been kept open by some such means, coupled with the constant disintegration of their sides. See Helland in *Quarterly Journal of the Geological Society*, Vol. XXIII., p. 142; and Bonney in *Geological Magazine*, 1877, p. 273.

† This is the French word, and the term universally employed by English writers, to designate the ice rivers with the nature of which we were first made acquainted by authors in that language. In German and Danish (Norse) they are *gletschers*; in Spanish, *ventisqueros*; and in Italian, *ghiacciaja*. But in various local dialects they receive different names. Thus in Carinthia they are known as *kees*; in the Pyrenees, as *serneille*; in Norway, as *iisbræ*, or *iisbrede*; in Iceland, as *fall-jökul*; in Piedmont, as *ruize*; in the Valais, as *biegno*; in some parts of Italy, as *vedretto*; in Lapland, as *geikna*; in Greenland (Eskimo), as *sermik-soak*; in Tyrol, as *ferner*, from the name applied to the névé (*firn*), &c.

slowly creep on with a flow like that of some viscous body, though the ice of which they are composed is hard and brittle, cracked and fissured in every direction by the strain to which it has been subjected in moving over the uneven ground, or by being precipitated over precipices in the course which the glacier has taken. Over its surface is spread the winter's snow, which in the summer melts and courses in streams, which tumble through

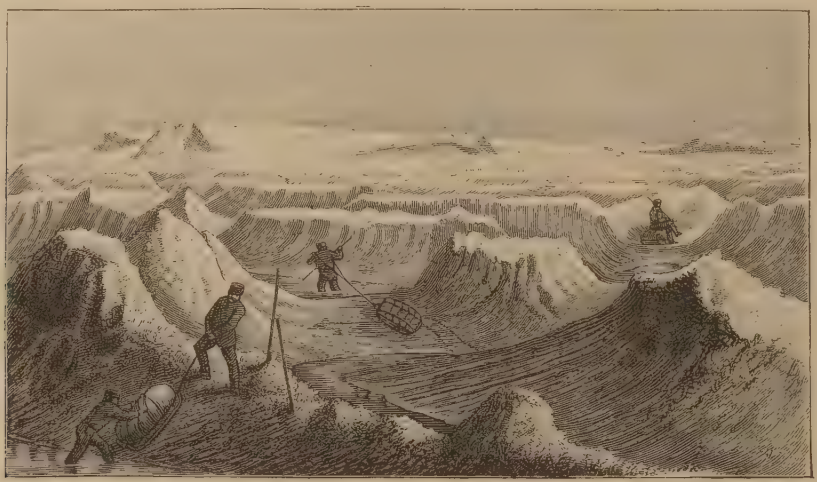


Fig. 190.—THE "INLAND ICE" AS SEEN IN SOUTH GREENLAND, WITH THE "NUNATAKS," OR PROJECTING ICE-BARE PEAKS OR ISLANDS, APPEARING IN THE MIDDLE OF IT.

the cracks and find their way from under the glacier in a rivulet rendered milky by the mud which it has washed from under the ice. This mud is for the most part due to the erosion of the great ice file which is imperceptibly grinding its way into lower elevations, until the heat of the valley gets too much for it, and the waste at the lower end counterbalances the supply of ice which is being manufactured in the névé reservoir above the snow-line. On its surface also are rocks, earth, and other *débris*, which have tumbled from the sides of the valley through which it flows, and various other materials which will be presently noticed (Fig. 189).

In addition to these *primary glaciers*, which occupy entire valleys often when the valley is deep and with a slight fall to the depth of 1,500 or more feet, there are *secondary glaciers*,* which fill the top of tributary valleys, of a steeper type, and of a less extensive character. But whether primary or secondary, the glacier is always moving, the mass in front being propelled by the mass accumulating in the rear, while the névé is ever passing by pressure and alternate melting and freezing from the state of granular snow into that of ice, just as the half-thawed snow on the street is soon pressed by the traffic into a similar substance. And certainly once seen, a glacier is a spectacle not soon to be forgotten. In Arctic lands the sight is sufficiently impressive. But the contrast between the ice rivers and the ice-bare country is there less impressive than in more southern regions, for the sea into which, in the far north, the glacier creeps is for the most part choked-up ice, and the land is seldom altogether clear of snow. There, indeed, the icebergs (Fig. 185) which break off from the seaward ends of the glaciers are even more remarkable than the gigantic glaciers themselves, though not equal in weird strangeness to the vast ice-

* The *Hängegletscher* of the Germans.

covered interior of Greenland, which is the reservoir from which the greater number of the glaciers seen in coasting the shores of that country proceed. In the south, however, the glaciers are startling by their very contrast to the peaceful scenes through which they creep. After walking through a wood, or up a slope gay with Alpine plants (*See* Coloured Plate), or over a rich pasture dotted with cattle, the pedestrian is startled by a chill expanse of ice filling a valley, and, though seemingly still, actually moving. Sometimes a glacier and a vineyard will be in such close proximity that the transition from the dismal glacier and the regions of eternal snow to the semi-tropical vegetation which it almost touches, might become the text for an instructive lesson in physical geography. (*See* Coloured Plate of the Glaciers of the Sind Valley in the Himalayas).

Fig. 191.—THE MER DE GLACE, NEAR CHAMONIX, SWITZERLAND. (*From a Photograph.*)

Motion of Glaciers.—A glacier has been compared to a river which drains away the snowfall which is not melted, evaporated, or got clear of by the wind sweeping it away or the avalanche sending it down the mountain side. In reality it is a river composed of snow, which has become converted into ice. At first sight it seems to be stationary. After, however, the position of objects on the surface of the glacier is compared with that of fixed landmarks on its sides, the river is seen to be moving. This motion varies at different seasons, and in different places, though with these limitations, the rate at which the ice rivers move is known to be very uniform. The motion of the different portions agrees with that of the different portions of a river (p. 291). James Forbes ascertained that the ice of the Mer de Glace of Chamonix (Fig. 191) advanced on an average 209 feet per annum at the source of the Arveyron, while the annual progression at

the base of the Montanvert was nearly four times as great—namely 822 feet. In spring and summer the motion of a glacier is more rapid than in winter, and, as we have seen, the motion of the different portions varies considerable. For example, to cite Forbes's classical observations, the mean daily rate of the Mer de Glace is, in summer and autumn, from twenty to twenty-seven inches in the centre, and from thirteen to nineteen and a half inches near the sides, so that a lump of rock which fell on its upper part in the year when William of Orange landed at Torbay, would only now be in the Valley of Chamonix. It has, however, been noticed that in the Arctic regions —in Greenland for example—the discharge of ice from the interior ice-fields is much more rapid. Take Jakobshavn ice fjord in lat. 69° 13′ N. as an instance. Here the vast inland ice (Fig. 190) is constantly relieving itself in the shape of icebergs, some of which are close on 400 feet high, and occasionally even higher. The breadth of the fjord, or rather of the glacier occupying it, is about 14,760 feet, and the dip of the glacier is less than half a degree. Its central part, at a distance of 3,280 feet from the sides, advanced during the summer when it was studied by Helland at the rate of 65½ feet per diem, while at the distance of between 1,312 and 1,476 feet its velocity was reduced to 49 feet per day. Finally, close to the sides, the mass moved at no greater speed than a little over half a foot a day. The "inland" ice which projects into the southern branches of the Jakobshavn Fjord, fifteen miles from the main glacier, moves at a speed not exceeding a foot and a third, or a foot and a half, a day.*

Crossing the American continent we reach the great glaciers of Alaska Territory, the most remarkable of which is Muir's Glacier, one of many which enter the sea at Glacier Bay. The water is deep up to the very edge of the ice, which Mr. Seton-Karr describes as rising like a broken wall, from which a shower of icebergs of various size is constantly falling into the ocean which laves its foot and undermines its green and glassy features. Glacier Bay is thirty miles long and eight to ten miles wide. At its mouth is a cluster of thirty islands named Beardslee, composed of glacial *débris*. The width of the ice where the glacier breaks through the mountains is 10,644 feet, and of the water front one mile, being in places as much as 400 feet high. Nine large and seventeen smaller branches unite to form the main ice stream, which to the extent of a current 5,000 feet wide and 700 feet deep, enters the sea during the month of August at the rate of seventy feet a day in the centre, and ten feet in the margin.†

On the other hand, many glaciers do not advance more than 10, 12, or a few inches a day (those of the Aar progress no faster than 55 feet in a year), the speed of an ice river being, to a large extent, dependent on the angle of its slope and the mass of material which is pressing from behind, the enormous speed of the glaciers of Alaska and Greenland being due to the latter fact, though the former is not without its influence on them. If the slope is only about 3°, then the motion of the glacier must be quick, above 8° or 9° the motion is hardly that of an ordinary glacier, while if the gradient is as high as 25° or 30° the flow is simply, as an eminent authority has said, "a mere silent cataract of fragments."

The *cause* of the motion has been the subject of many works, and is still the theme of much hot discussion among the adherents of the rival theories put forward. Saussure, the father of all Alpine exploration, attributed the advance of glaciers entirely to the me-

* Helland: "Om de iisfyldte Fjorde og de glaciale Dannelser in Nordgrönland" (*Archiv for Mathematik og Naturvidenskab*, I., p. 36) (1876); Rink: "Danish Greenland" (1877); and Hammer: *Proc. R. G. S.*, 1882, p. 235, for a fuller account of these remarkable observations.

† Wright in *American Journal of Science*, Jan. 1887; Seton-Karr: "Shores and Alps of Alaska" (1887) p. 38; Russell: "Existing Glaciers of the United States" (*U.S. Geological Survey*, 1883-84, pp. 309-355); *Alpine Journal*, Vol. XII., pp. 229-30.

chanical pressure exercised by the masses of snow in the rear, pushing forward the glacier, while the forward end melted away. This is the "Gravitation theory." Charpentier and, afterwards, Agassiz, looked to the alternate freezing and melting of the rain and snow that enter the fissures, as the motive power which propels the glacier forward. This is the "Dilatation theory." Lastly, not to mention several other views, Forbes regarded a glacier as a sluggish ice stream, which, though brittle, just as wax is brittle, has the power of accommodating itself to the irregularity of the bed along which it flows, this plasticity being of much the same character as that which enables a stick of sealing-wax to bend if laid across a beam until it is in a curve, though not broken. His doctrine has been termed the "Viscous" or "Plastic theory."

To a certain extent there is some truth in all of these theories, though none of them are exclusively true. Without entering into this vexed question, which is still far from settled, we may state briefly the view most generally espoused. Glacier ice, it is known, is plastic under pressure, such as that which enables the snow of the névé—or end of the glacier above the snow-line—to be squeezed into ice, but it is not plastic under tension, it will not bear drawing out into filaments like wax, borax, or bitumen. But if two fragments of ice are put together they will immediately freeze into one, even though brought into contact in water as hot as the hand can bear. "Plasticity" and "regelation" are thus the factors in glacier motion. The ice moves down a slope partly impelled by the masses in the rear. But the continuity of the stream is maintained by the broken fragments immediately freezing together when they are pushed against each other. So much is this the case, that when a glacier is squeezed into a narrow gorge and is compelled to take a leap over a precipice, the broken ends re-unite in the valley below, and continue their course as an apparently unbroken mass.* Even when the upper portion of the glacier tumbles over an escarpment in a cascade of detached blocks, forming a regular ice cascade of an irregular kind, the stream heals its scars, and rolls on in as solid a mass as before.†

Crevasses.—In flowing through a valley the glacier is subjected to stress, which causes it to fracture and form fissures, which often gape for great distances, and when covered over with a slender bridge of snow constitute in spring-time one of the chief dangers attending glacier travelling. These "crevasses"‡ are usually transverse (Fig. 192) to the direction of the flow when the glacier passes over an inequality in its bed. But they may take other courses, the course of which depends on the nature of the obstruction, the change of slope, &c. Marginal crevasses may also result from the friction of the ice stream against its banks. These fissures however, owing to this fact, and the consequent more rapid flow of the central position, will usually leave the side at a moderate angle and tend to run up stream. Crevasses are, however, no sooner formed than, by the motion of the glacier and the action of regelation, they begin to close, and other rifts to form in the mass as it passes over the same or similar obstructions, the noise caused by the tearing asunder of the great ice river echoing like thunder claps far and wide among the lonely Alpine valleys.

Fig. 192.—CREVASSES IN GLACIERS.

a, Transverse crevasses; *b*, longitudinal crevasses.

The Surface of the Glacier.—*Moraines.*—In grinding through a valley, the glacier

* In the Alps these re-cemented glaciers are known as *glaciers remanies*.

† For other theories see Croll: "Climate and Time" (1885); Mosely: *Proceedings of the Royal Society*, 1869; James Thomson; *Ibid.*, 1856–7; Tyndall: "Forms of Water" (1872); etc.

‡ French: In German *Schrunde* or *Gletscher-spalten*.

is apt to detach from the banks against which it presses, rocks, earth, or other materials. Or those materials loosened by the winter's frost, the spring thaws, or the summer rain, tumble down on the glacier beneath, and are carried on with it. In this way the sides of glaciers are littered with a more or less continuous line of such *débris*, which are known as the *lateral* (or side) *moraines*.* But when two glaciers from different valleys meet and coalesce, then (Fig. 193) the con-

Fig. 193.—GLACIER MORAINES.

s, Lateral moraines; *m*, Median moraines; *e*, Terminal moraines.

tiguous lateral moraines unite to form a *median moraine*,† which extends in a long wall of rubbish along the centre of the united glaciers. This arrangement might be duplicated, and triplicated, indeed—were the valleys frequent enough—almost indefinitely, with the result of the glacier being eventually lined by a corresponding number of median moraines, all of which being carried on by the glacier are ultimately deposited by it at

Fig. 194.—SECTION OF GLACIER MORAINE.

its termination, forming these *terminal moraines*,‡ which are so characteristic a feature of some Alpine valleys. Indeed, it is easy to trace the existence of long extinct glaciers by these great ramparts of earth, gravel, and rocks, brought from the upper regions of the mountains, and lying like some rude rampart athwart the valley, at the point reached by the vanished ice river on the surface of which they were carried. In addition to these moraines (Fig. 194) there is also a considerable quantity of earth, sand, and even stones, carried along by the under surface of the glacier. To this not very well marked detritus—which, when light, is to a considerable extent washed out by the stream which flows under it—the term *moraine profonde* § (deep moraine) has been applied, and an identity attempted to be traced between it and the "till" or boulder clay of our valleys.

The Waste of Glaciers.—This is continually going on, not only at the end where the progress of the ice river is arrested by the heat of the lowlands into which it has protruded, but on the surface also. During the height of summer, streams of water from the melting ice and snow are continually coursing over its surface, forming on the great glaciers of the north little lakes, and on the smaller ones of the south, cascades, by falling with a sullen roar into the crevasses which run athwart their course. Sometimes they fill up the fissures, and thus form what are called *baignoirs*, or baths. But in many instances they penetrate through the whole thickness of the glacier, and appear at the lower end of it in the shape of that milky stream which escapes from under the ice, and forms the head waters of so many rivers, the Rhône and Ganges (Fig. 177) among the number. In this case, from its likeness to the stream of water which drives a mill-wheel, the water tumbling down a crevasse is called a *moulin*.‖ A glacier, accordingly, owing to the waste which goes on, decreases in thickness every year, so that its lower portion is thinner than its upper—in other words, it is wedge-shaped, this thawing off being increased by the fact that the lower down a glacier reaches the greater must be its waste, since the heat increases every yard it advances. The rays of the sun are hotter, the warm air with which it comes in contact greater in its melting power, and the rain generally heavier

* German: *Gandecken.*
† German: *Gufferlinien.*
‡ German: *Stirnwall.*
§ German: *Grundmoräne.*
‖ German: *Trichter*, a funnel, or a mill-hopper.

than in loftier elevations. There is also a certain waste going on at greater depths: the soil wears away the ice by friction, and the streams which course under it being warmer than the ice, also help in the work of ablation. Finally, the springs, often much higher in temperature than the surface water, aid in the work of what Forbes called "glacier subsidence." In most parts of Switzerland, during the height of summer, the daily average ablation is 3·62 inches; the daily subsidence 1·63 inch. But during winter, whilst the glacier is covered with snow, the subsidence is suspended, and some portion of the summer waste is recouped. At this season the baignoirs and moulins are closed, and the whole mass of ice becomes more consolidated, so that ablation is reduced to a minimum. These facts, thus stated in their barest outline, explain several features seen on the surface of glaciers to which we have not yet referred. These are ice tables and gravel cones.

Glacier Tables.—There are often seen laying on the surface of a glacier slabs of stone supported by pillars of ice. These "glacier tables" (Figs. 189, 195)* are due simply to the protection which the stone affords against the heat of the sun. The ice on every side melts away, but that portion

Fig. 195.—GLACIER TABLE.

under the slab remains until it forms a pillar, capped by the stone, just as we have seen that earth pillars are produced in a similar manner by the capping stones protecting the pillar from the erosive action of rain (Figs. 138, 139). These ice pillars vary from a few inches to a height of 12 feet when the capping stone is very broad. Tiny tables may even be produced by leaves and other materials accumulating in sufficient quantity, though these are usually blown or washed away, so that a fallen leaf, a dead insect, or a little stone, so far from protecting the ice, by getting heated, forms a hole into which it sinks.

The share which *moulins* have in making "pot-holes" has already been noticed (Fig. 160), and those in the glacier gardens of Lucerne described (p. 311).

Gravel Cones.—Though these features are by no means so common as glacier tables, they may be seen in many places, particularly on the Aar Glaciers, where their character has been carefully studied. Externally they appear like mounds of earth and gravel, but internally they are composed of ordinary glacier ice. Their origin is not far to seek. When the glacial streams begin to course over the surface, they carry with them a good deal of the detritus washed out of the moraines, and deposit it either in the inequalities of the ice or at the bottom of the crevasses into which they tumble. By-and-by, owing to the superficial waste of the glacier, these heaps are exposed, on account of the general surface of the ice being depressed to their level. The cone is due to exactly the same cause as that which forms the pillar of the glacier table. The earth on the outside of the ice protects it from melting, and from the waste which would ensue were it exposed to the dash of the summer rains. Cones are also sometimes due, as glacier tables are, to a mass of moraine falling bodily into a crevasse, or sometimes even to rocks which have got embedded

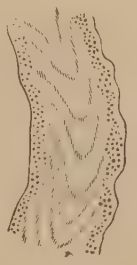


Fig. 196.—DIRT BANDS OF GLACIER, SHOWING THEIR SUPERFICIAL FORM AND THE COURSE OF THE STRUCTURAL LAMINÆ.

in the under surface of the glacier; though on this subject, as well as on the means by which they are forced to the surface, there is

* German, *Gletschertisch.*

considerable difference of opinion. In this way also knapsacks, hammers, and other objects which have fallen into crevasses have, after the lapse of a number of years, been disgorged. The most remarkable instance of this was that which occurred in 1860, when a well-preserved corpse, clothed in mediæval costume, was thrown up by the Ahrenthal Glacier in the Eastern Alps.

Structure of Glacier Ice.—The ice of a glacier proper differs considerably in structure from the stratification of the névé in which it originated. Examined in the wall of a crevasse, it is seen to be streaked with beautiful vertical veins, like the "cipollino" marble of Italy, the laminæ varying in hue from bluish-green through green to white. They are usually parallel to the sides of the glacier, though rather inclining from the shore to the centre of the ice stream. On the surface of the glacier — at intervals of some hundreds of feet—there are superficial discolourations in the form of excessively elongated hyperbolas. These are due, according to the observations of Forbes, to portions of the ice in which the veined structure is markedly developed, and when, by "the decomposition of the softer laminæ, portions of sand and dirt become entangled in the superficial ice," thus giving rise to the phenomena of "dirt bands" (Fig. 196), which thus display the exact course of these hyperbolas on the surface of the glacier. This laminated, ribboned, or banded structure, produced by the alternation of thin plates or strata of ice different in colour from that of the rest of the glacier—which is whiter, owing to its being more porous—is due, as Tyndall's experiments proved, to pressure. It may therefore be regarded as analogous to slaty cleavage (p. 112).

Fig. 197.—"PIERRE DES MARMETTES," AN ERRATIC GRANITE BLOCK OR "FOUNDLING" AT MONTHEY, IN THE LOWER VALAIS.

Erosive Power of Glaciers.—The power of glaciers to grind, like their power to bore or gouge, has been the theme of not a little hot discussion. Some observers will have it that though they scrape and polish to a great extent, they do not dig deeply. "They are," according to Mr. Freshfield, "not so much the sculptor's workman as the sculptor himself. Their share in hill structure is to give it artistic merit: to round a corner and polish a boss." In proof of this, the fact is adduced that

in Alaska, Muir's Glacier passes over a forest buried in sand without having disturbed it. In this instance, however, the ice had been partially supported by a spur of rock, and therefore its whole weight had not pressed on the sand,* though cases might be cited which could not be explained away by a fact like the one mentioned. On the other hand, whenever a glacier has passed for any length of time, we find the rocks worn and grooved; and when bosses of hard rock have lain in their way, these *roches moutonnées*,† or sheep-like rocks, peep above the pastures in which they now lie as monuments of a former age.

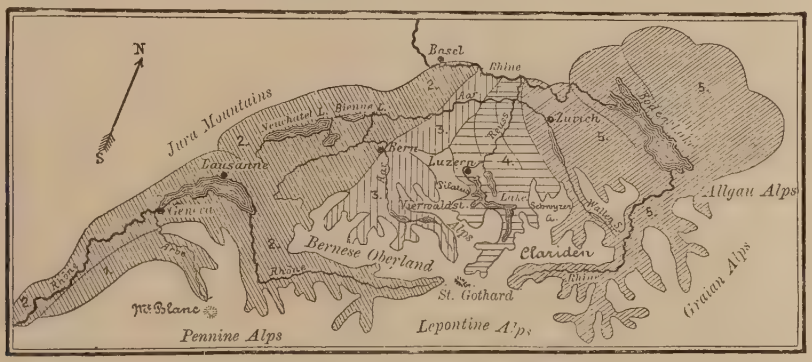


Fig. 198.—THE OLD GLACIERS OF SWITZERLAND.

1, The Arve glacier; 2, The old Rhône glacier; 3, The old Aar glacier; 4, The old Reuss glacier; 5, The old Rhine glacier.

When the ice stream has been obstructed by an outlying crag, like that on which Edinburgh Castle stands, it grinds in front of the cliff, and then sweeps behind it the *débris* it has worn out; just as a stream which finds a boulder in its course washes out everything in front of the obstacle, and sends a tail of sand and gravel from the other side where there is quiet water. This phenomenon is known as "crag and tail."‡ When stones are embedded in the under surface of the glacier, the amount of erosion which it accomplishes must be infinitely greater. It is these stones which cause the furrows or "gletscherschliff" of the hard granite and gneiss; in any softer rocks the grooves would soon get effaced.

Retreat and Advance of Glaciers.—The length of a glacier is usually very uniform over a long course of years—the waste at the lower end being compensated for by the supply of material from the upper termination of the great ice river. This, however, is not always the case. Little glaciers of the secondary order sometimes contract remarkably, and, if from any reason the reservoir is drained without a fresh supply of snow making its appearance, vanish. If, on the other hand, there is an addition to the material which makes up the body of the glacier, it will advance, pushing before it the old moraine, and remorselessly effacing turf, stones, châlets, and every other obstacle in the path of the "tongue." Such a case occurred in 1818, when the terminal moraine of the Rhone glacier, from under which issue the beginnings of the Rhone,§ advanced 150 feet.

The opposite is, however, more frequently

* Wright: *American Journal of Science*, January, 1887; and Freshfield: *Proceedings of the Royal Geographical Society*, May, 1887.

† German: *Rundhöcker*.

‡ In "Science for All," Vol. V., p. 47, Professor Duns discusses this subject very fully. See also two papers in Vol. I., p. 29, Vol. II., pp. 187 and 267 of the same serial, by Mr. J. E. H. Gordon and Professor Barrett, on the subject of ice and glaciers.

§ The people of the valley, however, regard the three warm springs which rise at the back of the Hôtel du Glacier du Rhône (5,751 feet above the sea), to the left of the Post Station, as the true sources of the river.

true. For instance, the glacier of La Brenva, on the south side of Mont Blanc, continued to shrink from 1818 to 1878, and in the interval from 1854 to 1865 the Glacier des Bossons, also in Mont Blanc, retreated 1,089 feet, and that of Four 1,706 feet. Since 1855 the glaciers of the Pyrenees and the Caucasus have also been observed to shrink. But a shrinkage is generally followed after a time by an advance. The Pasterzen glacier, which was yearly on the retreat, began, in 1883, to slightly advance, and a similar forward movement is said to be observable in those of Mont Blanc. For example, the lower extremity of the Glacier des Bossons is steadily keeping towards lower and lower levels, its inferior extremity having for the past three years advanced at the rate of over 160 feet a year. A grotto cut out of the ice in May, 1866, a quarter of a mile from its termination, has moved down more than 180 feet. The lower Grindelwald glacier is the lowest in the Alps. Until recently it terminated at 3,409 feet above the sea. But after a period of retreat it has again begun to advance. Indeed, between 1871-75 in all the chains of the Alps there was not a single known glacier which had not decreased in size. Nearly all of these have, however, again begun to advance. But the glaciers of the Rhine and the Aar are still at the stage of shrinkage, and so are most of the glaciers of Glarus and the Grisons, as well as those of the Austrian Alps.* This advance is due to a greater amount of snowfall in its upper regions; its retreat to the opposite cause, combined with an increase of temperature in the region into which it advances.

Fig. 199.—NEWLY-FORMED "FLOEBERGS" IN ROBESON'S CHANNEL DURING THE WINTER OF 1875-76.

(*After Nares.*)

In the Alps the glaciers keep more than 3,000 feet above the sea; in the Arctic regions they reach the sea—as, indeed, they do in one place in Norway, and in several places in Alaska. But at some former period in the world's history, which we shall have occasion to speak of at a later stage in our studies, glaciers existed where none are now found, their existence being traced by the grooved and polished rocks, the old moraines and

* Forel: "Les Variations Périodiques des Glaciers des Alpes" (1885).

the erratic rocks — what the Swiss call "foundlings"—the remains of ancient moraines which have been left perched on the sides of the valleys through which the vanished glaciers ground, or, as in Scotland and other parts of the world, dropped by icebergs which had floated over the surface, at that time under the sea (Figs. 197, 198, and

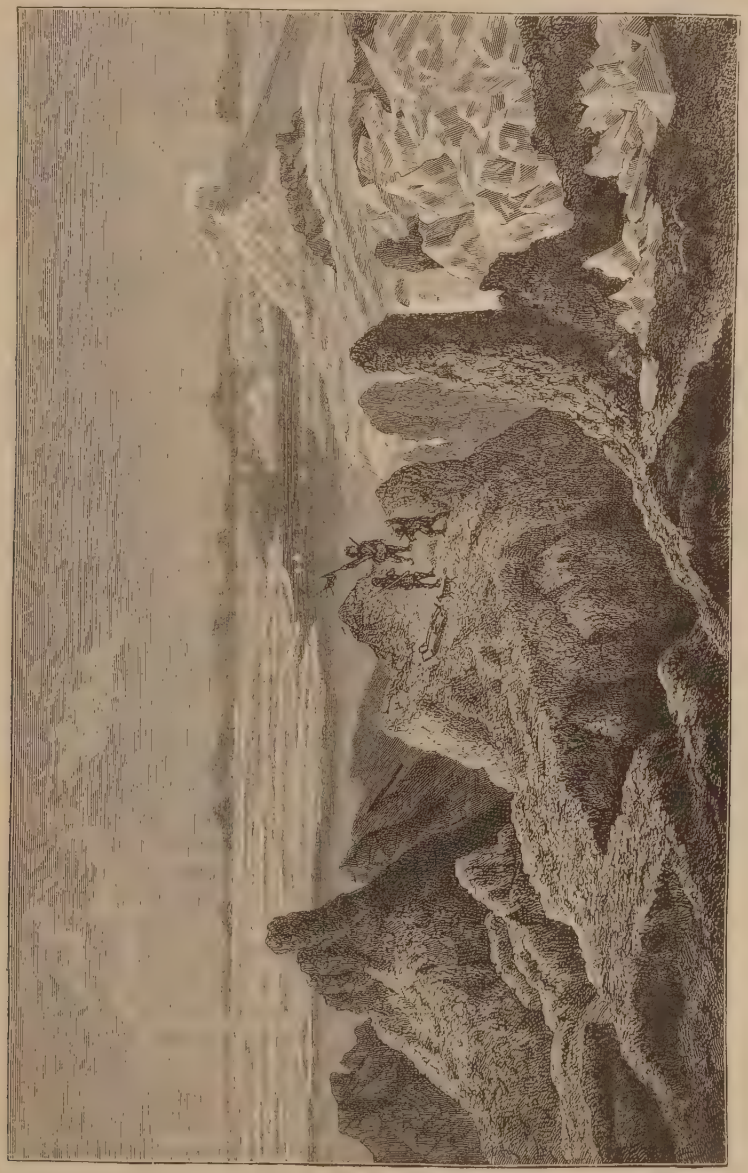


Fig. 200.—CAPE FLIGELY (PAYER'S MOST NORTHERLY POINT IN FRANZ JOSEF'S LAND.)

Coloured Map, showing the Past and Present distribution of Glaciers).*

Polar Glaciers.—These in their geological relations may, perhaps, be better studied when the Glacial Period is under consideration, since during that age of the world's history, the regions subjected to it were, in many respects, the counterpart of those from which in the Polar regions icebergs take their origin. In every other respect the Polar glacier is the same as the Southern one, only that while the latter rarely reaches the sea the other invariably does, and relieves itself not by melting, but by breaking off in the shape of an iceberg (Fig. 185). These icebergs are the seaward ends of glaciers, which are the overpourings of a vast inland expanse of ice (Fig. 190). This ice, so far as we know, covers the entire interior of Greenland, and is seen in caps over other Arctic islands.

In many respects the inland ice is the most remarkable feature of the Arctic regions. In South Greenland it does not approach within a hundred miles or thereabouts of the coast; but in North Greenland its borders can frequently be seen from the sea. But wherever found its general features are the same. In South Greenland there are one or two "Nunataks" (Fig. 190), or islet-peaks, projecting above the surface of the ice. These are evidently remnants of the old land surface, which have not as yet been overwhelmed by the garnered snows of unnumbered ages. But wherever the country has been penetrated elsewhere, after the ice-free stripe of land along the coast has been passed, nothing except one vast expanse of glacier ice has been seen. In early summer this is of course covered with snow. But as the long Arctic day advances, the surface is coursed by streams of water, which in the hollows of the ice form lakes often of considerable extent, or thunder with a sullen roar through the vast crevasses which intersect it in every direction, though as the interior is approached these fissures become less frequent than when near the coast.

On the whole face of the earth there is perhaps no drearier region than this inland ice of Greenland. Eastward the vision is bounded by a misty horizon terminating in ice and unobstructed by any sight or sound, which reminds one of the land which is fading behind the explorer as the land fades behind the voyager who sets sail on the ocean. North and south the same dismal landscape meets the eye. Here and there in holes in the ice a few specks may be detected. These are found to consist of kryokonite (p. 68)—a minute mineral, whose origin it is hard to trace—of a few specks of meteoric dust, and some exceedingly minute beaded plants of the conferva order, such as not unfrequently occur on snow. But there is no trace of moraine, which, one would imagine, would be found if the ice in its course across the country had ever come in contact with mountains or exposed land.

We are therefore led to the conclusion that the inland ice of Greenland is due to the immense accumulations of snow during fully three-fourths of the year not being melted during the brief summer (during which, on the coast at least, little or none falls), without the intervention of a mountain range, as in the case of more southern glaciers. In brief, the snow acts like the grain emptied out on the floor of a barn: the surplus slides in the shape of glacier ice to the east coast on one side, and the west coast on the other, from the elevated plateau of the far interior. At one time, perhaps, a range did exist, as, no doubt, hill and valley did; but long ago they have been overwhelmed, as there is every reason for believing Scotland, among other countries, was during the last Glacial Period.

As we advance from the coast to the interior the elevation gradually increases. How high the plateau is we cannot say, for, though Greenland is fully 1,400 miles long and 900 broad at its widest, no one has as yet penetrated more than 130 miles from the coast on the west side, where the ice is nearer the sea than on the east. There, from the farthest point reached by Lieutenant Payer

*Penck: "Die Vergletscherung der deutschen Alpen" (1882); Heim: "Handbuch der Gletscherkunde" (1885), etc., etc. A fair list of recent publications may be found in Günther's "Lehrbuch der Geophysik," Vol. II., pp. 564-568, though with some omissions so extraordinary as to suggest doubts as to its value.

and party up Franz Josef's Fjord, the inland ice was not seen. Several attempts have been made to investigate this Arctic mystery—in one of which the writer shared*—but those expeditions which were fortunate to reach farthest are to be credited to Baron Nordenskjöld and his companions. The first of these was in 1870, when, after a journey of almost thirty miles, they reached a point in lat. 68° 22′ N., about 2,200 feet above the sea. In 1883 he succeeded in reaching a spot eighty miles from the edge of the ice,† and his Laps pushed on until they stopped at a point computed—too liberally, I believe—to be 130 miles from the sea. The ice was then 6,000 feet high, and still rose gradually to the east, but no peaks were visible. The continent has thus been crossed for so considerable a distance, that, if there were any peaks of much magnitude—such as Payer's and Petermann's Peaks on the east coast—they could hardly fail to have been visible. But "the inland ice," writes this famous explorer, "continued to rise towards the interior, so that the horizon to the east, north, and south, was terminated by an ice border almost as smooth as that of the ocean." This inland ice is of unknown thickness; but, from observations made at places where it reaches the coast,‡ it has been estimated to be frequently from 1,000 feet to 3,000 feet deep.

There is, therefore, in Greenland no névé in the sense we understand by this term in the Alps. At the extreme limit of Nordenskjöld's second excursion he found a tract of slushy snow and water, which was manifestly the neutral border between the zones of waste and growth, for that season at least. Throughout his journey, except in the last few miles, he encountered a surface covered with kryokonite and pitted by superficial melting, which had manifestly removed not only the last season's snows but was working into the old ice. On the other hand, the Laps, who advanced into the interior for over fifty miles farther, found unmelted snow prevailing, and were driven back from want of water, indicating that they had reached the true névé. We may, therefore, take it for granted that in mid-Greenland the neutral zone lies approximately one hundred miles distant from the edge of the *mer de glace*.§

Yet in spite of these very patent facts, Baron Nordenskjöld formulated the theory that beyond this dreary expanse the country is entirely free from ice, and probably wooded, being warmed by the southerly wind which reaches the interior as a dry breeze. To confirm this theory his expedition of 1883 was undertaken, though its main result—it is perhaps unnecessary to say—was simply to confirm the view it was intended to disprove. Curiously enough, General Greely has also taken up this notion, from finding ice-bare spots in the interior of Grinnell Land. But this gallant officer never saw the inland ice of Greenland, or he could never have confounded it with the totally different feature of the western shores of Smith's Sound.

In the South Polar region (Fig. 8) the icebergs are flat-topped, and, it is affirmed, sometimes 800 feet high, the ice evidently sliding off flat islands; in the upper reaches of Smith's Sound similar "floebergs" (Fig. 199) have been seen, due, no doubt, to similar causes.

The Arctic iceberg is the seaward end of the glacier which has protruded under the sea, buoyed up by the water until it detaches itself. But it has been virtually detached long before it reaches the sea, the great crevasses being the means by which the size of icebergs is fixed. The sea only serves to float away what has already been separated from the parent glacier. The size of bergs therefore varies infinitely. The loftiest of which we have any accurate measurement is one mentioned by Hayes, which was 315 feet above the water, ‖

* Brown: "Das Innere von Grönland" (Petermann's *Geographische Mittheilungen*, October, 1870); and "Arctic Papers of the Royal Geographical Society," pp. 1–74.

† In about lat. 69° 30′ N., long. 40° W.

‡ Hammer: *Proceedings of the Royal Geographical Society*, 1882, pp. 235-7; K. J. V. Steenstrup: *Meddelelser om Grönland*, Fjerde Hefte (1883), pp. 71–112.

§ On this subject, and its bearings on geology, see Chamberlain and Salisbury's admirable memoir in *United States Geological Survey*, 1884–85, pp. 205–322.

‖ Rink has calculated that about one-seventh of the bulk of an iceberg is above water, and six-sevenths below it.

and rather more than three-quarters of a mile long, and was calculated to weigh 2,000,000 tons. But as the size of a berg is dependent on the height of the glacier end from which it "calves," and as this may—as in the case of the Humboldt Glacier—be sixty miles broad, it does not often happen that they can be the whole height and breadth of the "sermik-soak" or great ice wall of the Eskimo.* As these Arctic glaciers are rarely more than short tongues from the inland ice, it also seldom happens that they carry loads of moraine. Moraine is, indeed, rarely seen on the Greenland glaciers, and when there is any, it is usually capsized in the terrible turmoil which accompanies the birth of an iceberg. Moreover, by the waves constantly wearing away their base, bergs so frequently capsize after they are free that the end uppermost is rarely the end which formed the upper surface of the glacier. The fantastic figures which appear in books have seldom any counterpart in Nature, for it is the fashion of artists to take liberties with Nature and to group the exceptional bergs as if they were commonly seen together. Yet among the vast fleets which are constantly seen sailing out of Jakobshavn Fjord, hard by which the writer lived for a summer, may be witnessed ice mountains of shapes quite as fantastic as any which the imagination of the draughtsman has grouped together. Finally, it may be added, that the mud-laden subglacial rivers are filling up the Greenland Fjords, as they have filled up many of the Norwegian ones, with a fine laminated clay—in which shellfish burrow—undistinguishable in its character from the brick clays of Scotland and other parts of the Northern Hemisphere. This adds one more proof that the laws of Nature have never altered, that the old order changeth not, and that to understand the Past we must look to the Present, instead of inventing hypothetical cataclysms and catastrophes, which both in kind and in degree are exceptional in the World's history.†

* An iceberg described by Ross and Parry was 2½ miles broad and 153 feet high; so that, assuming the form to have been approximately that of a cone reared on an elliptical base, it has been calculated that the ice above water would be something like 150 million tons, and that the entire mass weighed not far from 1,500 million tons. Even after allowing that the dimensions given for some of the Antarctic icebergs—800 to 1,000 feet high, and nearly 3 miles long—are exaggerated, it is impossible to assign to them exactly the same origin as those of the Arctic regions; though, as we have indicated (p. 375), this is a difference more nominal than real. Northern icebergs have been known to float as far South as lat. 36° N., while those of the South Polar Region have been seen off the Cape of Good Hope in lat. 34° S.

† In addition to the works already mentioned, the reader may be referred for further particulars regarding Polar ice to three papers by the late Dr. Moss, R.N., of the Arctic Expedition of 1875–76, and the author in *Science for All*, Vol. I., p. 33, Vol. II., p. 356, and Vol. V., p. 328. Professor James Geikie's "Great Ice Age" also contains an admirable account of most glacial phenomena, though that of the Greenland ice is more imperfect; while the works of Baron v. Nordenskjöld, especially in their English translations, must be read with much caution, as his theories are open to question, and his statements are not always as accurate as he seems to consider those opposed to his views erroneous. Greely's volumes are valuable, though he is in error regarding the inland ice of Greenland, which he never saw, and appears to entirely misapprehend. Payer is good, so far as he goes, but Nares and De Long are rather meagre, and not always right.